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THE SIDEREAL MESSENGER
NAME OF THE FIRST TEN VOLUMES.

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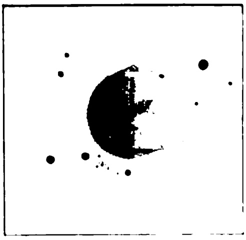
Fig 1.



Nov. 11, 1892, 10h 30m

Fig. 2.

Dec. 10, 1892, 8h

Sketches of Holmes' Comet by H C. Wilson at Goodsell Observatory.

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Astronomy and Astro-Physics.

NEW SERIES, Vol. XII, No. 1. JANUARY, 1893. WHOLE No. 111

GENERAL ASTRONOMY.

ON THE PROBLEM OF THE SOLAR MOTION.*

TRUMAN HENRY SAFFORD.

In some papers presented in 1874 and the following year to the American Academy of Arts and Sciences at Boston, I pointed out that the hypothesis which makes the stellar distances on the whole inversely proportional to the star's proper motion is far more probable than that which assumes that these distances are a function of the star's magnitude. We can at once see the disagreement between the facts of the solar system and a hypothesis like the latter; while the nearest planet to us is also the brightest the most distant one is by no means the faintest; and there is no very definite relation between distance and brightness in the cases of Mars, Jupiter, and the asteroids.

On the other hand the average rapidity of angular motion among the planets as seen from the earth is more definitely connected with the distances.

In testing the theory that the star's distance is roughly a function of the annual proper motion, I very soon found that the individual discrepancies were pretty thoroughly masked by the general law when the stars were grouped by tens or twenty-fives according to the magnitude of their proper motions. In other words the average parallax of a group of twenty-five stars whose proper motions are nearly equal, but whose positions are in widely different parts of the heavens will (very nearly) be the same fraction of the annual proper motion as holds good for another group of stars of nearly equal proper motion, one-tenth as great as in the first group. The reasoning upon which this conclusion was based is derived from a study of that fraction of the total proper motion which simply reflects the Sun's motion towards Hercules and Lyra.

Mr. W. E. Plummer, in 1883, while investigating the Solar motion from the southern proper motions determined at the Cape of

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* Communicated by the author.

Good Hope (see vol. 47 of the Memoirs of the Royal Astronomical Society, pages 340 to 343), adopted my hypothesis and compared it with the other; and found my conclusions sustained.

In 1890 appeared Dr. Stumpe's investigation of the Solar Motion (vol. 125 of the *Astronomische Nachrichten*), which led by a different way to about the same result. We may then consider the hypothesis as highly probable; and that the dependence of distance upon apparent magnitude is much less so; because in the earlier investigations the sum of squares of proper motions is very slightly diminished, on the whole, on the one theory; and by a large percentage on the other.

My present object is to point out what I think the right way to proceed in future.

We can, without hesitation, transform our coördinates in such a manner that the pole of the system, or axis of Z, shall be in an assumed direction of the Solar motion. This direction is now known within a few degrees. The advantage of this process is that the material shows its character more distinctly; the motion from the pole toward which the Sun is moving is at once seen to prevail, on the average; and the effect of the slight corrections to the direction of this point, afterwards to be applied, can be readily calculated. The transformation of coördinates thus indicated is analogous to that well-known one in orbit work when the plane of the approximate orbit is made the fundamental plane, a transformation which, in 1859, I believe I was the first to employ.

In studying the gradual decrease, along with proper motion itself, of the reflection of the solar motion, it is necessary to employ the smaller proper motions as well as the larger. Dr. Stumpe went down to $0''.16$ yearly. Argelander in 1830, went as far down as $0''.09$; and for Bradley's stars it is quite probable that the lower limit might now be no more than $0''.05$ or $0''.06$. But a careful investigation needs to be made of this lower limit, as it is dependent upon the observations available, and in some degree on the constant of precession; so that the systematic corrections and probable errors of the different authorities, and the corresponding weight, need to be taken account of in making the necessary least square solution. The investigation is one which requires a great deal of patience.

In determining star-places for practical purposes we frequently obtain proper motions which cannot be considered certain. That is, the value obtained by a least square solution, is less than its probable error, or does not much exceed it; a fair enough limit would be to consider all proper motions as trustworthy which are greater than five times their probable error. In this case a star 3 times observed by Bradley in declination would usually be considered as in motion in either direction if the difference between Bradley and a thoroughly good modern determination was 4″ or more. And intermediate authorities would usually be found sufficient to confirm the motion. At the present time Piazzi and Groombridge, if errors of reduction are detected, are also old enough to give many accurate proper motions; and the best of the work done before 1850 is so much more precise that a good many stars not previously observed can be employed by careful re-determination. The least square combination of all, if proper weights are used, and systematic corrections applied, is still better.

The end to be attained is to thoroughly test the law of average distance, in inverse proportion to proper motions, down to the smallest certain values of the latter element. If we can do that, we can fairly assert that we know something about the average distance of a good many of the stars.

THE ANDROMEDES.*

J. MACLAIR BORASTON.

Though much disappointed by cloudy sky off the Azores obscuring the Leonids on the 13-14th November, the magnificent view of the Andromedes obtained last evening (23-24th November) more than made good the loss.

The observations were made on board the steamer "Don" in longitude 72° W., and latitude 17° N., south of Hayti, and consequently $4^h\ 48^m$ behind Greenwich mean time.

The radiant point was for a large portion of the six hours of observation so well elevated that the best position for watching the short-track and stationary meteors in order to fix it was found to be upon one's back.

Observation was commenced at 7 P. M. local time $= 11^h\ 48^m$ G. M. T., and a continuous watch kept up till $1^h\ 0^m$ A. M. 24th No vember $= 5^h\ 48^m$ G. M. T.

The great elevation of the radiant point, combined with a cloudless tropical sky, the absence of moonlight, and the unobstructed view of the complete hemisphere, afforded the *ne plus ultra* of astronomical requirement.

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* Communicated by the author.

The intersection of some 70 short-track meteors about the radiant point, together with four coincident stationary ones, fixed the latter at R. A. 28° + 36°, about a fourth of the wav from 56 Andromedæ towards β Trianguli. It has been determined in ignorance of any recorded radiant; in fact the shower had been by some means entered for the 29th November, and was only heralded by its own appearance.

Counts were taken at intervals in all parts of the heavens for areas of 60° = $\frac{1}{6}$ of the visible hemisphere, and for a duration of 5 minutes each. From these counts which were remarkably equal at all times and in all parts of the heavens, 18 meteors per minute come out as the average per area. As the shower was proceeding with undiminished energy after 6 hours of observation, the total number during these six hours may be set down at 108 per minute for the entire hemisphere, which gives 6,480 per hour, and a grand total of 38,880. This is certainly a minimum, for many of the faint, rapid meteors must have escaped notice, a safe inference from the number only just caught before extinction.

The heavens were alive in all parts, and every variety of meteor present, from the trackless stationary ones in the radiant-point to the the luminous pear-shaped 'drops' at the horizon, whose tracks often extended from 20° to 30° in length, and remained visible for roughly ten seconds after extinction of the meteor itself.

The shower must have extended into the opposite hemisphere, for when the radiant point occupied the zenith, the meteors ran down to the horizon; and when, after some hours it had declined appreciably westward, they still fell little short of it on the eastern horizon.

Several faint, swift, long-track meteors traversed the radial paths of the Andromedes proper, sometimes absolutely tangential to them, and, without exception (so far as could be observed) well removed from the radiant point. In fact they generally cut at about a right angle the paths of the slow, long, orange-track meteors occurring at about 50°-90° from the radiant point from which they were further differentiated by their swift motion, dull tracks and absence of anything like a visible head.

A further observation at 4:00 A. M. = 8^h 48^m G. M. T., showed the shower still active on that side of the heavens where the radiant point lay, though unfortunately cloud prevented systematic observation. Supposing the shower to have maintained its original activity, this would yield a total little short of 60,000 meteors for the hemisphere.

Why should these meteors appear so much brighter at a distance from the radiant point than in its vicinity? As the latter was near the zenith throughout observation, absorption would operate less effectually for meteors occurring there than for those at the horizon; add to which the fact that the tracks are seen more or less end-on, and one would expect that the compression of the light into a smaller area would render them more brilliant. This was unequivocally *not* the case, and instances of conformity rare. Short, sharp, dull tracks were the rule about the radiant, long slowly-developed brilliant yellow-to-red tracks as the horizon was approached. The solution may be that the former class are of small mass and are promptly disintegrated in the higher strata of the atmosphere, consequently suffering little displacement from the radiant-point. The enfeebled resistance of the atmosphere at the higher levels would also account for their rapid motion and retention of the original direction of. approach, whilst the small quantity of matter and rarity of surrounding atmosphere might be expected to yield the dull tracks observed.

On the other hand, supposing the long luminous meteors projected to the horizon to be of large mass, their apparent deviation from the original line of approach might be due to their having on that account entered the lower atmospheric strata, and the increased density of the latter would tend to retard their motion, and to set up more active combustion. But as the greater combustion is balanced by a larger supply of material, the tracks are not only brilliant, but long. The theory would seem to be further borne out by the insignificant or invisible head of the meteors in the neighborhood of the radiant, whilst those distant from it have generally large heads.

The memory of the 1892 Andromedes will remain long with me. The sight was one of the grandest I ever beheld: the perfect sky setting off the glories of Taurus, Orion, Canis, Argo, and other gems in the great belt, itself crossed in the zenith by the Galaxy, full of light; the symmetry in the development of the meteor tracks consequent upon the location of the center of radiation directly overhead; the multiplicity of motion and the underlying unity of principle,—all tended at once to stimulate and satisfy the mind.

JAMAICA, 25th November, 1892.

THE STAR OF BETHLEHEM.*

J. G. PORTER.

The Star of Bethlehem most naturally presents a subject of absorbing interest to the devout scholar, for its certain identification with any astronomical phenomenon, the occurrence of which could be definitely calculated, would not only afford a strong confirmation of the historical accuracy of the early records of Christianity, but would also throw a flood of light on some still unsettled questions of chronology. So much has been written on the subject that there would seem to be little left to say. In fact, in THE SIDEREAL MESSENGER for September, 1887, there is a full statement by the editor of what is known concerning the history of that memorable star. The results of the careful study made by the author of that article may be summed up as follows: "Of the Star of Bethlehem astronomy claims to have no knowledge. The latest study of the Christian astronomer leads to the belief that the wonderful star-like appearance at the birth of Christ was a phenomenon wholly miraculous."

With this conclusion I heartily agree; and the subject might well have been allowed to slumber for a time, but that no less an authority than Professor John N. Stockwell in a recent number of the Astronomical Journal again revives the planetary conjunction theory of Kepler, and proceeds to discuss it in a most interesting and able manner. He attempts to show that "the Bible narrative concerning the star in the east is better satisfied by a conjunction of Venus and Jupiter than by any of the conjunctions computed by Kepler." The conjunction here referred to, took place according to Prof. Stockwell's computation May 8, B. C. 6, and the planets were very close together, being about half a degree apart. Of course, they would present a most striking appearance in the morning sky, rising a couple of hours before the sun. In conclusion he says: "This close conjunction of Venus and Jupiter—a happy combination—the symbols of love and beauty associated with dignity and power—was a fitting announcement of the birth of a Prince who was to bring peace on earth and good will towards men, and is perhaps the strongest corroboration of the truth of the Biblical narrative concerning the origin of the Christian dispensation that has yet been found, having a purely scientific basis."

It seems almost a pity to criticise a theory which accords so

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* Communicated by the author.

well with the desires of the devout mind, but I can not bring myself to regard this explanation of the phenomenon as at all satisfying the plain requirements of the Scripture history. In the first place, the wise men came from the east to Jerusalem, that is, in a general westerly direction. Prof. Stockwell assumes that the declaration, "we have seen his star in the east," refers to the location of the star and not to that of the observers. But if they saw the star in the east, why were they led to go westward in search of the Prince whom the star announced? It seems far more natural to suppose that the star which appeared to them in their native east guided them towards the land of Palestine, and must therefore have been in the western sky. In the next place, this assumption is rendered still more probable by the latter part of the Bible narrative which Prof. Stockwell fails either to quote or to explain. When they left Jerusalem "the star which they saw in the east went before them till it came and stood over where the young child was." At the time of the conjunction in question Venus had passed her western elongation and was approaching the sun. During the time occupied by the journey of the wise men, not only would the planets have separated in the sky, but Venus would be farther east and would only be visible for a short time before sunrise, and hence could not possibly have appeared to go before them from Jerusalem to Bethlehem, a direction nearly south. Nor does it seem to me that any heavenly body would meet the required conditions, for the Magi were perfectly familiar with the effects of diurnal motion, and even though the star might happen to stand over Bethlehem at the time of their arrival, they would know as well as we that it was purely accidental, and that a little earlier or later it would occupy a different position in the heavens. Here then seems to be an instance where we can not eliminate the miraculous from the Bible account, but must conclude that the Star of Bethlehem, like the Herald Angel, was a messenger directly from the realm of the supernatural.

Cincinnati Observatory, Dec. 5, 1892.

THE SOLAR CORONA OF APRIL, 1893.*

J. M. SCHAEBERLE.

Nearly three years ago I advanced a theory of the Solar Corona which practically accounts for the coronal forms observed.

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* Communicated by the author.

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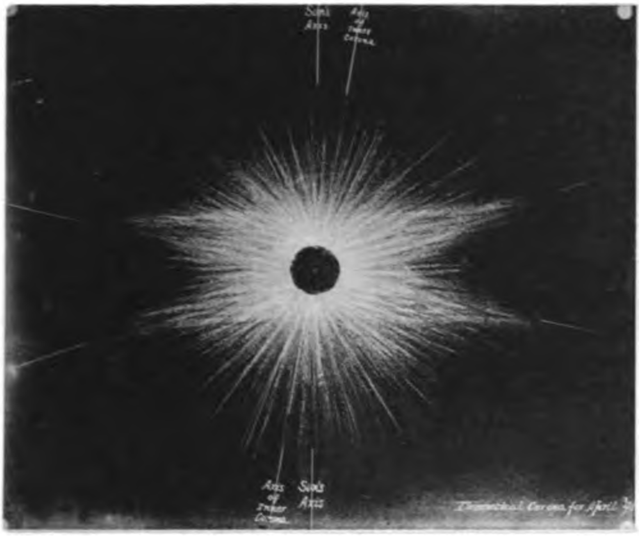
Sun's Axis
Axis of Inner Corona
Axis of Inner Corona
Sun's Axis
Theoretical Corona for April

difference is evidently due to the smaller magnitude of the stars in the Pulkowa Catalogue which contains very few stars brighter than the fourth magnitude. It contains however, more than 400 stars of between the fourth and the fifth magnitudes, and these gave almost exactly the same standard motion as those of the same magnitude in Auwers' Catalogue, viz., about 0''.220. But upwards of 1,000 stars whose magnitudes ranged between the 5th and 6th gave an average standard motion of about 0''.275 The stars between the 6th and 7th magnitudes gave a still higher result but they were comparatively few in number and probably selected in many cases on account of their large proper motion. To ascertain whether the increase was continuous I tried the stars from magnitudes 4 to 4.5, and from magnitude 5.0 to 5.5 separately. The result was that the former gave an average standard motion of about 0''.200 and the latter of 0''.250. Whatever the cause may be the increase would, therefore, appear to be progressive for the two magnitudes from 4 to 6. The most probable cause is I think, loss of light in traversing space, owing to which as the distance of a star increases, the apparent magnitude diminishes in a more rapid ratio than that of the inverse square of the distance. But errors of observation and computation must be considerably reduced before we can draw any such inference with safety.

Comparing the spectra of the stars there were some remarkable changes chiefly arising from the notation of the Draper Catalogue. The distinctions drawn in that catalogue are too numerous to be carried out in the case of faint stars; and accordingly we learn from the introduction that "nearly all the fainter stars have been classed as A, E, or H, the additional lines, if present in the spectra, not being detected in the photograph owing to small dispersion." This will account for why the stars of the types B, G, I, K and M with which I have to deal are less numerous than in Auwers' Catalogue, being largely absorbed by the classes A and H. The spectrum F, however, occurs more frequently than E in the catalogue with which I am dealing. Owing to the increased standard motion of the fainter stars the figures arrived at for B, I, K and M may be too low (the G's are not numerous enough to draw any inference). The stars of class B however which number 41 exhibit the same extremely small proper motion as those in Auwers' Catalogue. The average standard motion determined in the same way as before is only 0''.100, or taken arithmetically about 0''.113. This is less than one-half of the average for stars with the spectrum A, (I have in all cases discarded the notes of interrogation in the Draper Catalogue.

[illegible]

[illegible]

[illegible] The difference between the spectra A and B is somewhat similar to that between F and K or M and in both cases the star with the greater number of lines in its spectrum appears to be the most brilliant. Cooling apparently leads to the disappearance of some lines and the narrowing of others—probably by the condensation of the absorbing vapors or their sinking beneath the photosphere.

We are not, as yet, I think, in a position to make accurate numerical computations on the subject nor have I leisure (even if I possessed the requisite mathematical skill) to make them. But a rough estimate of the relative brightness and nearness of the different classes of stars can be made wtihout difficulty. Comparing the relative brightness of the various binary stars in Mr. Gore's Catalogue, I find for the mean of the Sirians 14.00 and for that of the Capellans 2.10. These means were determined in the manner already indicated. Now, assuming equal masses and densities, a star with the latter relative brightness should be brought 2.58 times nearer to us in order to appear of the same photometric magnitude with the other. I find that the average standard motion of the Sirian stars (spectrum A) in the Pulkova Catalogue is about 0.225″ and that of the Capellans (spectra E and F) is about 0.675″, the ratio being thus nearly 3 to 1. Assuming the real velocities to be equal, a Capellan star is thus, on the average, about 3 times as near to us as a Sirian star of the same magnitude. This agrees as well with the former result as could have been expected, and I think we shall not be far astray in concluding that, assuming the masses and distances to be equal, a Sirian star will appear at least two magnitudes brighter than a Capellan. Arcturian stars apparently occupy a position about half-way between. It is, no doubt, possible to invent other explanations of both series of facts. The larger proper motions of the Capellan stars may result from greater actual velocity in space or from the Sirian stars generally having a motion in space in better agreement with that of the Sun than the Capellans. The phenomena of binary stars may be explained by assuming that the Capellan stars are, on the average, of much larger mass than the Sirians, for large mass would reduce the proportional amount of illuminated surface and accelerate the revolution of the system. But we must adopt different explanations in the two cases and neither explanation rests upon a basis of observed facts. I therefore prefer the explanation which depends on the relative brightness or dullness of the illuminated surfaces—a brightness or dullness which we might naturally expect to find associated with the nature of the spectrum.

It is perhaps too soon to place the various kinds of spectra enumerated in the *Draper Catalogue* in order of greater or less illumination of surface, but I think the following arrangement will be found not far from the truth (the brightest being placed first) B, A, M, K, I, H, G, E, F.

TWO LARGE TELESCOPES.

A. A. COMMON.

Of the propriety of the appeal which Professor Pickering* makes there can be no doubt. It is very rarely that one can be made on

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* Referring to Professor E. C. Pickering's circular concerning a large southern telescope.

such absolutely good grounds as this rests upon. From such an instrument in such a climate, under such admirable direction, most valuable and interesting results may with certainty be looked for—results of great importance to the astronomer, and which will be a source of great gratification to the donor of such a happily favored telescope. I sincerely hope that Professor Pickering will be successful in his appeal to his fellow countrymen.

With regard to the Paris telescope, the large size of the projected telescope over anything yet done makes the question of construction much more interesting. The largest silver-on-glass mirror yet made is my own 5-ft. From this to 10-ft. is a great step; from a focal length of 27 feet to 140 is a great leap. It brings us face to face with enormous difficulties, not perhaps insuperable if met in the proper way, but which may very easily become so.

I propose to briefly consider some of these and make a suggestion as to the best way to deal with them. Taking it for granted that the telescope, if properly made, will give results in light grasping power and definition in proportion to its size when compared with smaller instruments, and leaving out of consideration entirely the question of the suitability of the neighborhood of a large city as the site of a big telescope, with the remark that while I admit that the climate may not be the best possible, I should expect to gain in any given place by increasing the size and power of the telescope used whatever might be the advantages elsewhere.

As far as can be gathered from the English newspapers, the projected telescope is to have an aperture of about 10 feet and a focal length of about 140 feet—truly a gigantic instrument! Nothing has been said definitely about the style of mounting, but it is clearly meant that many observers shall be permitted to use the telescope. This last condition is of vital importance and affects the question greatly, for if the right kind of mounting is used to gain this end the whole thing becomes a feasible matter.

If it is intended, as I gather from what appears in this morning's '*Standard*,' to mount the telescope as an equatorial, with a cupola in the usual style, then I have no hesitation in saying that however well such an arrangement might do for one observer doing delicate astronomical work, it would be entirely unsuitable for giving many observers an opportunity of seeing any celestial object; to do this properly it will be necessary to resort to some modification of the altazimuth mounting, with the eye-piece coming through the trunnions on which the tube of the telescope rests.

The unsuitability of the ordinary form of equatorial mounting becomes apparent when we remember that in order to render the eye-piece available for any position slightly off the meridian the upper part must be rotated, and this in such a large instrument would have to be frequently done as the telescope moved in right ascension; then the observer would have to be carried round at an irregular rate at a height of some 150 feet on some sort of stage, that while safe enough for one or two skilful observers could never be used by the world at large.

By adopting some form of the altazimuth mountings already so well known, with suitable modifications, all these difficulties could be overcome and many advantages gained.

The best use to put such an enormous telescope as that already mentioned would probably be to devote it to a general survey of the most important objects; for this purpose its great focal length and light-grasping power would be very valuable, with an altazimuth mounting and a fairly approximate movement in the two planes an object might be kept in the field well enough for continuous eye-work, though not, perhaps, accurately enough for very delicate measurements.

Even if something more than the parallactic movement of the equatorial had to be given up, the great gain that results from the altazimuth form of mounting as regards the difficulty of properly and effectually providing for the comfort and safety of the observer would more than compensate for it.

Sir William Herschel's 4-foot telescope was mounted in a very effectual manner too well known to make a description necessary; it has served for a model of several other reflectors which have done admirable work, as, for instance, the telescope mounted on this plan used by Sir John Herschel in his survey of the southern heavens.

The observer, however, is in the open air and at a considerable height when the telescope is pointed to the zenith. The tube of the telescope is necessarily a closed one, and the whole of the mounting is exposed to the wind and the weather. This form of mounting is very well suited for making sweeps of a degree or two in altitude, allowing the objects to come into the field of view for observation without movement of the telescope in azimuth; but it does not lend itself to the continuous observation of an object, nor is the position of the observer a very good one.

The plan used by Lord Rosse in mounting the 6-foot telescope restrained the movement in azimuth to a comparatively short distance on each side of the meridian. The arrangements for the observer are slightly better for continuous work on an object within the range of the telescope in right ascension, enabling the study of nebulæ to be carried on in a better way than the mounting of Sir William Herschel's telescope permitted.

Mr. Lassell's four-foot telescope was mounted equatorially; but an inspection of the drawing of it and the observing tower is enough to show that the limit of size had almost been reached for that plan—a remark that also applies to the 4-foot reflector at the Paris Observatory. The earlier telescopes made by Sir William Herschel and, I believe, one made by Sir Isaac Newton, were mounted in a way that kept the eye-end at a fixed height. Miss Caroline Herschel's comet-sweeper was mounted in this way; but instead of moving the whole of the frame-work carrying the telescope in azimuth, Miss Herschel's telescope and the arrangements supporting it in altitude moved round on a central pivot. I do not know who was the maker of this particular form of mounting; it is certainly a most admirable form for the purpose for which it was made.

This plan of having the centre of motion in altitude close to the eye-end renders the position of the observer invariable as regards his height from the ground; his movement in following the telescope in azimuth is determined by the radius of the eye-end sweep which in cases under consideration would be about half the focal length of the telescope, a very small matter with a small telescope.

The largest telescope I know of mounted on this plan is that made by Dr. Draper, and so well described in his work on the construction of a 15½-inch silver-on-glass telescope, published by the Smithsonian Institution. Here we have a frame-work roughly in the form of a square, with the sides equal in length to the telescope; at one upper corner of the square the telescope-tube is swung in trunnions, one of which, being hollow, allows the light from the mirror to come to a focus just outside the trunnion—the telescope-tube being counterpoised by weights working at the end of bars supported at the diagonally opposite corner of the square to that where the eye-piece is situated, and connected to the mirror-end of the tube by wire ropes in such a way that their action is exactly equal and opposite to the weight of the end of the tube under varying angles, thus permitting the mirror-end of the tube to be raised or lowered while the eye-end remains at the same height.

In the case of Draper's telescope, the square frame-work carrying the tube and counterpoise weights was supported on a central pivot, and so the whole could be moved round as required. This, with the required inclination of the telescope-tube, allowed the telescope to be pointed to any celestial object without altering the height of the eye-piece, exactly as in Miss Herschel's telescope.

The observer was provided with a movable platform, which was quite independent of the framework carrying the telescope and could be moved to follow the eye-end of the telescope as required. The same part of the mirror is always uppermost in this form, and that makes the edge support much more easy than in the case of an equatorial, where the mirror may have any part of the edge uppermost.

There are many points about this form of mounting that are very good; one of the most important perhaps is the absence of heavy and costly constructional work. A very large mounting could be made very cheaply, using ordinary wrought-iron lattice-work girders and covering with thin sheet-iron—much the best material for surrounding a reflecting telescope. If it were decided to mount a reflector of the size given, I do not know any form that might be exactly copied so well as the mounting made by Dr. Draper. There is nothing impossible; but the large movement of the eye-end would be a source of inconvenience, as the platform would have to have a motion of varying amount to keep the observer within reach. In order to get rid of this trouble the important modification I would propose is to shift the pivot, which, as we know, is central in Dr. Draper's mounting, to a point exactly under the trunnions, balancing the frame-work by counter-poise weights. This could be very easily done by having a large *caisson* under, floating in water—the exact movement being kept correct by a strong central pin. We would have in this arrangement a frame-work similar to that of Dr. Draper, but turning on a pin or centre under the trunnions instead of under the centre of frame-work; the sweep of the eye-end would then be reduced from about 70 ft. (that is, about ½ the focal length) to about 7 ft. (that is, ½ the diameter of the tube *plus* a little for the projection of the trunnions). This frame-work with an open lattice-work tube with counterpoise arrangement would form the telescope proper, in place of a tube two lattice-girders on edge braced together at the top and bottom would connect the mirror and the trunnions, about the trunnions and for a little distance above and below there might be a tube connected by some flexible material to the portion of the frame-work near the trunnions, and the whole of the rest of the frame-work might then be covered in so as to form a large dark chamber in which the mirror would be free to work under the best conditions as regards freedom from currents of air; this would also form the best kind of workshop in which the mirror could be made, by having the machine for working it just under the end of tube when vertical, so that it could readily be taken off machine and attached to tube or taken off for silvering.

With such a great amount of surface the effect of the wind might be injurious as regards definition, and it might be best to have, covering the whole of what we might call the mounting proper, another frame-work running on outer rails and covered over so as to protect the mounting within. This outer frame-work would then surround the mounting, being made large enough to allow it to rotate in azimuth some 30°, so that the outer frame-work would only require movement at intervals of two or more hours. At the upper portion, where the tube of the telescope would project, the outer frame-work would of course be cut away to allow the telescope to move without touching it—a platform being built to come up close to the trunnion forming the eye-end and forming part of a chamber which could be of any desired size on the outer frame-work, access by any suitable means being provided on this outer frame-work. The movement of the trunnion with the eye-end being in a circle of about 7 ft. radius, would not be very great during the movement of the telescope during the two or more hours that it could be used without the movement of the outer frame-work.

This arrangement of outer and inner frame-work becomes very large, but it would answer admirably; nearly one-half becomes useless as regards sheltering the telescope and might be to a large extent dispensed with, the only objection being the great power the wind would have upon such a large surface rotating in one corner. This could be largely prevented by making the sides with considerable slope and having an arrangement for anchoring to the rails if necessary. As regards the actual amount of material required in the construction of the covering, this would be largely reduced, The inner chamber formed by covering the inner frame-work and forming the telescope might be obtained, not separately as proposed, but by using the outer frame-work and cover. We should then have a telescope of the following description:—An open frame-work in general construction very similar to that designed by Dr. Draper in all the important parts, excepting that the centre of rotation would be under the trunnions instead of under the centre of frame-work; this would have to be balanced, but with a large floating circular vessel there would not be any difficulty in doing that. This frame-work telescope would be covered by a strong outer frame-work of the shape on plan of a triangle, the apex being the centre of rotation of the inner frame and the base the line that the outer portion of this frame-work would sweep—say an angle of about 40° or 45°, so that the inner frame-work would be free to sweep through this angle without coming in contact with the outer one. The junction of the tube of the telescope near the trunnions with the outer frame could be made air-tight by any flexible material that would not communicate the vibrations of the outer frame-work to the telescope. The platform for the observer and his dark chamber, etc., could be of almost any size.

The mounting here suggested would enable a constant stream of visitors, if needed, to go up and down the outer frame-work without in any way interfering with the telescope: it would permit the mirrors to work under the best conditions, and, above all, it would allow the observer to work under the most favorable conditions, not only as regards his personal safety and comfort, but as regards the absence of that constant movement that is needed with the equatorial. In fact, a little consideration will show that, apart from the question of making a show telescope, this arrangement is really the best that could be used for a large reflector, which might be called an exploring telescope, and be used for many purposes and in many situations where the ordinary mounting could not be taken, owing to difficulties of transport.

As regards the mirror, although the increase from 5 to 10 feet is great, there ought not to be any great difficulty in casting and properly annealing the glass; that done, the rest is only a matter of time, care, and patience. There is not the least difficulty beyond the making of the glass that need cause any doubt as to the ultimate success. From the thickness found to be perfectly sufficient in the 5-ft. mirror, a thickness of from 10 to 12 inches for a 10-ft., would be ample.

Even if the idea of making this large telescope be abandoned, I hope that a similar one may be made on the lines I have suggested, as for a given amount of outlay it seems likely to give the best results, particularly in that general exploring work for which it is so peculiarly suited.—*Observatory*, November and December, 1892.

THE HOLMES COMET

As many questions have been asked and so much of interest [illegible] expressed about the new comet during the last two months that it seems best to give a brief statement relating to its characteristics and its history since the time of its discovery. This new comet was first seen Nov. 6, 1892, by Mr. Edwin Holmes, an amateur astronomer residing in London, England. On the evening of that day Mr. Holmes was trying to observe through a hazy atmosphere and as a test object he chose the small [illegible] in Andromeda. While moving his small telescope from the object above named he saw in its field a nebulous object which he soon satisfied himself was a new comet of considerable size and brightness. As quoted by the Observatory for December he said at the time: "This is something unusual and will be a big fellow and I must get a good look before I leave it if possible." Mr. Holmes wrote at once concerning his discovery to Mr. Maunder, Mr. [illegible] and Mr. [illegible] of [illegible]. He determined the place of the comet at the time of discovery as immediately preceding [illegible] and [illegible] was easily determined. [illegible]

The new comet was seen on the evening of the [illegible] of November [illegible] by Mr. K[illegible] and Mr. [illegible] of [illegible]. It was again seen on the 14th at [illegible] by Mr. Holmes and marked changes in appearance reported. The nucleus was much less distinct than one week before and much less bright, the boundary of the nebulosity less well defined and less perfectly circular. The intrinsic brightness was also less and the diameter was largely increased. Mr. Holmes' estimate of the size of the comet's head as seen in the field of the micrometer was, at that time, from 8' to 9' in diameter.

November 11, when Mr. Holmes reported his discovery to the *English Mechanic*, he said: "I think it the comet must have appeared suddenly, for I observed that region, October 25, and observed nothing special." As the position was in the direction from which Biela's comet might approach the Earth, Dr. Berberich of Berlin, a rapid and experienced computer, immediately called attention to this fact and some astronomers assumed the new comet to be Biela's and calculated the distance it should be from us, and the time it would cross the Earth's path. The results obtained from these computations indicated that the time the comet would cross the Earth's path was only a few hours from that when the Earth would surely pass the same point. Such statements in the hands of newspaper reporters quickly gained very wide circulation, producing the impression that there would be a collision between the Earth and the comet on or about the evening of Sunday, November 27, 1892. As a result something of a "comet scare" was experienced in some parts of this country that reminded one a little of the woeful events predicted for the comet of 1843 in the early part of that year. It must be confessed that there was some ground for apprehension in the public mind, from statements reported to have been made by some prominent astronomers. But when it was learned very soon after that their conclusions were based on incorrect or erroneous observations, none could be more ready or anxious to correct wrong impressions than were these same astronomers themselves. But, as error often outruns the truth for the time being, so in this case, not a few simple folk were doomed to the woes of fearful anticipation up to, and including, that Sunday night, that we suppose were only faintly represented by the political cartoonists in the newspapers of that date, who were trying to picture the just and speedy retribution of wicked opposing politicians. The moral of this is that astronomers should be more careful in the future for the sake of the reputation of the science, to say nothing of the harm of involving the innocent in jeopardy. To remind politicians incidentally of the possibility of an awful future for them may not be blameworthy. On the other hand it is a well-known fact that not a few persons did watch the sky faithfully on the Sunday night before mentioned in the expectation of seeing the comet and probably something of the startling phenomena predicted.

Another most interesting fact appearing nearly coincident with the Holmes' comet was the brilliant meteoric shower of Wednesday evening, Nov. 23, 1892. The display was remarkable in many parts of the United States and in some localities of Europe already heard from. The radiant point was in the constellation of Andromeda, and the rapidity with which the meteors fell is shown by statements from a few observers at different places mentioned below:

At Northfield, Minnesota, one person counted, on the average, 15 or 20 per minute. The display was from 7 o'clock P. M. until midnight.

From Princeton Professor Young reported that the meteors were already numerous at 7 o'clock, and from 7:30 to 12:30 when it clouded, they were falling at the rate of 100 in four or five minutes, and that within the range of vision of the place, the total number falling must have been at least 30,000 during five hours.

At Palo Alto, California, Leland Stanford University, Professor W. J. Hussey reported that a single observer could see 50 or 60 fairly bright meteors every five minutes corresponding to a daily rate of from 400,000,000 to 500,000,000 on the hemisphere of the Earth towards the radiant.

Professor Hussey fixed the radiant very closely, he thinks, at $\alpha = 1^h\ 39^m$; $\delta = +\ 42°$.

Professor Young determined the radiant roughly at 8:30, as being a circular area of about 4° in diameter whose center was $\alpha = 1^h\ 20^m$; $\delta = +\ 41°\ 30'$. At 10 o'clock it seemed to be more definitely limited and several nearly stationary meteors fixed it at $\alpha = 1^h\ 30^m$; $\delta = 40°\ 30'$. At 11 o'clock it was again determined at $\alpha = 1^h\ 40^m$; $\delta = +\ 40°$. From these observations a change in the position of the radiant seems possible if not probable, especially when compared with the results obtained by Denza referred to by Professor Young in his note on the meteoric shower (p. 943, Dec. 1892, A. A.-P.). He there suggests the important query whether a recession of the node can be accounted for by perturbations since the year 1885.

Holmes' comet was barely visible to the naked eye on the evening of this display and was about 10° west and 4° south of the radiant.

It is, so far as known, the general belief of astronomers that this grand display of Nov. 23 was none other than that of the Bielid meteoric stream which has been one of special interest for twenty years past. As Professor Young says, if this swarm is moving in the path of the Biela comet, then its period of revolution must be 7 years instead of the 6.6 years which was the period of the Biela comet. Either the swarm is a new one or the orbit of the old one is changed, or possibly still the dismembered fragments of the old Biela comet have more divergent paths for separate swarms of meteors than is known from existing records of this Biela family. These recent phenomena of the meteors will certainly interest the students of this branch of astronomy, and we shall hear from them further, doubtless at an early date. It is now certainly known that the new comet, is in no way at all connected with the late meteoric shower, except accidentally to appear nearly at the same time in very nearly the same place in the sky. Knowledge of the elements of the orbit of the comet was determined by computers less quickly than usual in the case of new comets because in obtaining an approximate parabolic orbit unusual difficulties were met by experienced computers in satisfying the middle place. It therefore became necessary to wait for observations at wider intervals, and then only elliptical elements would answer the degree of approximation sought for reasonable verification. Several such sets of elements have been computed by European and American computers, two of which are given below. A study of the elements of this comet's orbit will reveal some most interesting features.

The comet appears to belong to Jupiter's numerous family of comets having the aphelion point of its orbit just inside the orbit of that planet at a distance from the Sun represented 5, or five times the mean radius of the Earth's orbit. Its perihelion is at a distance of 2.17 with a longitude of 349°. The eccentricity of the orbit is remarkably small—only 0.39. There is no other known comet orbit that is so nearly circular. The aphelion distance being small this comet ought to be followed throughout its orbit by the larger telescopes, certainly. If this be true the perturbations by Jupiter, as suggested by Schulhof, may be studied with special advantage.

It is also a noteworthy fact that the comet's orbit lies wholly within the minor planet belt, as is shown by its small inclination to the ecliptic. Its motion is direct, and its orbit one of extremely small eccentricity and unusually short period of revolution around the Sun.

Two sets of elements show these facts, and indicate other points for further study. Those by Rev. George M. Searle published Nov. 21 are:

$$
\begin{array}{rl}
T = & \text{Oct. } 11.9802 \text{ G. M. T.} \\
\left.\begin{array}{r} \omega = \\ \Omega = \\ i = \end{array}
\begin{array}{rrr} 42^\circ & 19' & 02'' \\ 325 & 41 & 16 \\ 19 & 16 & 43 \end{array}\right\} & 1892.0 \\
\log a = & 0.525258 \\
\log e = & 9.504648 \\
\text{Period} = & 2241 \text{ days.}
\end{array}
$$

Those by A. Berberich of Berlin published Nov. 27 are:

$$
\begin{array}{rl}
T = & 1892, \text{ June } 20.7357, \text{ B. M. T.} \\
\left.\begin{array}{r} \omega = \\ \Omega = \\ i = \end{array}
\begin{array}{rrr} 18^\circ & 12' & 14.8'' \\ 331 & 4 & 23.2 \\ 20 & 39 & 38.8 \end{array}\right\} & 1892.0 \\
\varphi = & 23 \quad 9 \quad 0.6 \\
\mu = & 523''.335 \\
\log a = & 0.554151
\end{array}
$$

Under date of Dec. 3, 1892, Mr. Searle reports that he has computed a set of new elements for the comet from observations of Nov. 8, 16, and 24, the last of which was later found to be inaccurate, so the new elements have not been published. These elements indicate a period of 6¾ years and a time of perihelion passage in the month of August, 1892.

Elsewhere in this issue will be found a detailed description of the observations and drawings of this comet made at Goodsell Observatory of Northfield, Minn. Plate I shows some of the sketches from Dr. Wilson's note-book.

SOME RECENT MARKINGS ON JUPITER.*

MARY W. WHITNEY, VASSAR COLLEGE OBSERVATORY.

During the past October and November, observations upon surface features of Jupiter have been made at our Observatory with the twelve inch equatorial. The atmospheric conditions have been on several evenings remarkably good and we have secured better views of Jupiter than I have ever before seen. A similar series of observations was carried on a year ago. I send some of our best views, as drawn by my assistant, Miss Wagner.

The red spot has suffered a striking change since last year. It has grown larger, much fainter and more diffused. It is too faint to show decisive color, at least to my eye. In good seeing, the following edge was comparatively well defined, but the preceding edge was never seen in clear outline, Fig. 5. It would seem by its present appearance to be breaking up. Its upper and lower edges generally seemed to lie against the neighboring belts, though a few of our sketches show a clear space between it and the southern belt, in which it lies. At times it has struck us that this line of separation was more plainly discerned when the spot was coming on or passing off than when near the central meridian.

The great southern belt has changed little in its general contour since last fall. The slope in which the red spot lies preserves about the same angle. We have observed various white spots within this belt, generally elongated in form and very elusive. They have been far more difficult to hold than any other of the white spots we have seen. Three of our drawings of views not including the red spot show an almost continuous light streak running longitudinally through the belt. This was seen only at

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* Communicated by the author.

PLATE III.

Fig. 1.

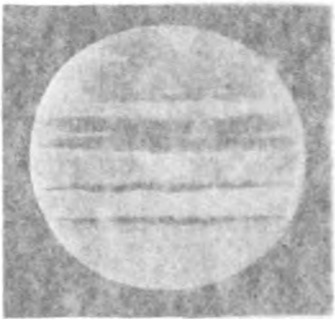

Fig. 2.

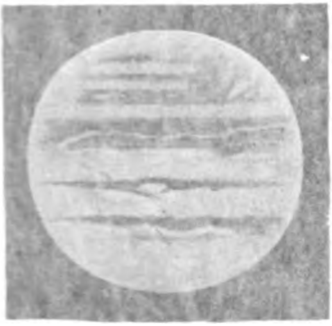

Fig. 3.

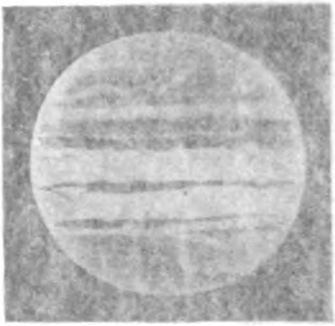

Fig. 4.

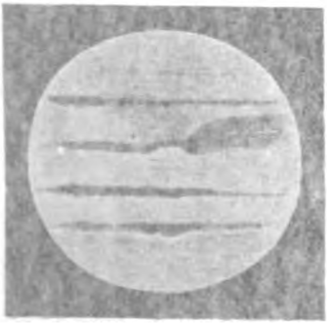

Fig. 5.

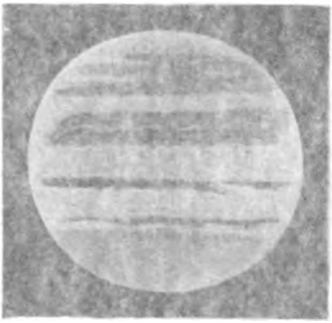

Fig. 6.

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[illegible] observations [illegible]
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[illegible] observations upon [illegible] [illegible] Observatory [illegible] [illegible] conditions have [illegible] good and we have secured [illegible] been seen. A [illegible] a year ago. I send some of [illegible] assistant Miss Wagner.

[illegible] change since last year. It [illegible] decreased. It is so faint [illegible] even in good seeing, the [illegible] defined, but the preceding [illegible] fig. 5 [illegible] would seem by its [illegible] Its upper and lower edges [illegible] neighboring belts, though a [illegible] space between it and the south- [illegible] It struck us that this line [illegible] only discerned when the spot was [illegible] when near the central meridian.

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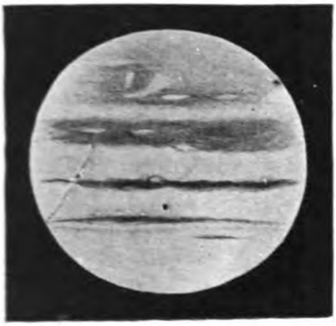

FIG. 1.

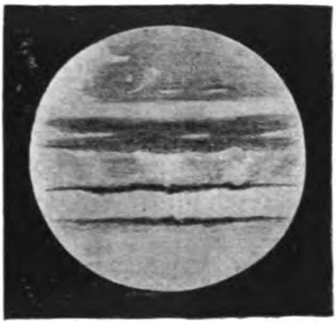

FIG. 2.

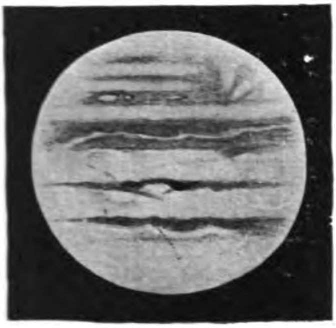

FIG. 3.

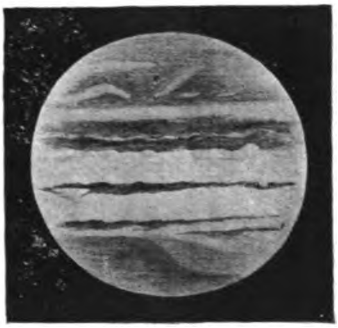

FIG. 4.

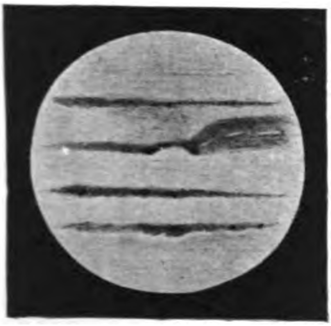

FIG. 5.

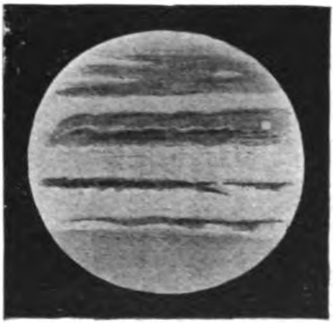

FIG. 6.

[illegible] Mr. [illegible] that he has [illegible] for the comet [illegible] observations [illegible] which was later found to be [illegible] have not been published. [illegible] years and a time of perihelion [illegible] 1892.

[illegible] a detailed description of [illegible] of this comet made at [illegible] Plate I shows some of the [illegible]

[illegible] ON JUPITER.

[illegible]

November, observations upon [illegible] our Observatory [illegible] The atmospheric conditions have [illegible] good and we have secured [illegible] before seen. A similar [illegible] a year ago. I send some of [illegible] assistant, Miss Wagner.

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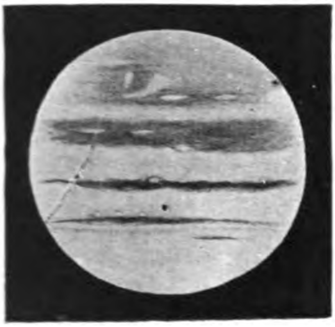

FIG. 1.

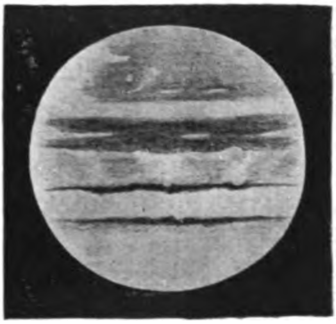

FIG. 2.

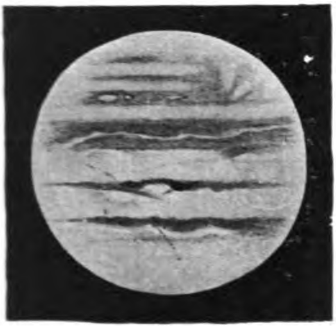

FIG. 3.

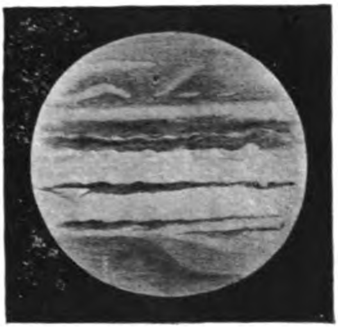

FIG. 4.

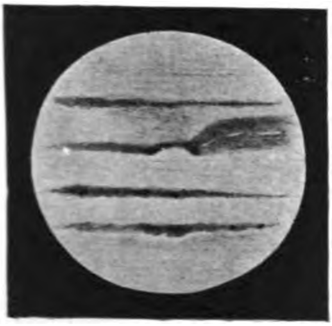

FIG. 5.

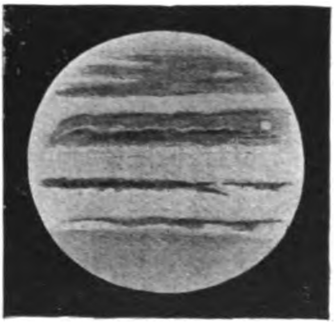

FIG. 6.

times and under the best conditions. On Nov. 11th a similar rift was noted in another part of the belt, at the point where it again widens, after the narrowing which accompanies and precedes the red spot. Perhaps this may presage a separation of the southern belt into two. We have noticed also that the northern border of this belt just following the red spot sloped southward, out of parallelism with the north belt. The concavity shown in Fig. 5 with the dark spots preceding and following was noted on other dates, Oct. 28 and Nov. 11th.

On several evenings we have obtained very fine views of this belt, giving the effect of cumulus clouds with beautiful light brown shadings. On Oct. 26, when the seeing was exceptionally good, we called these shadings pink.

The Northern belt has been conspicuously darker than any other throughout our observations. It has shown considerable variation, presenting dark spots and breaks more or less extensive. On Nov. 11th, Fig. 6, it was entirely broken asunder at one point. We have noted white spots above and below this belt, but at no times within it.

The southern cap, as we call it, frequently looks like two or more belts, the lowest of which lies against the red spot and shades a little lighter than the great southern belt. This bordering belt, however, does not extend around the planet. We have seen it only on the side with the red spot. This cap has contained white spaces more irregular in form than any other we have observed. The figures represent some of our clearest views of these markings. They have been quite persistent and have predominated on the side opposite the red spot, *i. e.*, on the side where the lower edge of the cap has not shown the belt-like appearance. Might not these facts, if further substantiated, have some bearing on the effect of the great red spot on the cloud masses lying south of it?

The northern cap has been more uniformly shaded than the southern. It has shown irregularities, as in Fig. 4, but no defined spots.

The Northern white belt has been brighter than the others. We have not been able to detect any shadings upon it.

THE PROBABLE ORIGIN OF HOLMES' COMET.*

SEVERINUS J. CORRIGAN.

The comet discovered by Holmes at London, Eng., on Nov. 6, 1892, and which has attracted universal attention of late, has presented features so anomalous that it may be regarded as a body unique among the members, permanent or temporary, of the "solar system," and as one inviting the special investigation of astronomers, particularly as to its origin.

In the first place, while its slow apparent motion has so far prevented the computation of very accurate elements of its orbit, those that have been determined have shown clearly enough that it is a body which was at time of discovery, and is now, receding from both the Sun and the Earth, and that it was nearest to both long before Nov. 6, 1892; therefore it should have been considerably brighter, and larger in apparent dimensions some time before the date upon it was found by Holmes.

Now it is most remarkable, considering the assiduity and care with which the heavens are continually scanned, through powerful telescopes, by astronomers specially engaged in the search for comets, that this body which was quite visible to the naked eye shortly after the time of discovery, should have escaped detection long before it was found by Holmes, who has said that he had shortly before examined that region of the heavens in which he subsequently found the comet, and had observed nothing extraordinary therein. This sudden appearance in so prominent a shape is the first noteworthy peculiarity of this body.

Another anomaly is that while this comet was receding from both the Earth and the Sun, its apparent diameter increased in a most remarkably rapid manner, and that, while the increase was taking place, the brightness decreased.

The object of this article is to suggest a possible, and I may say a *very probable* cause for all these peculiarities. I believe, and I think this belief may be substantiated by subsequent observation and computation, that Holmes' comet had its origin in a collision of some two members (known or unknown) of the large group of asteroids which revolve around the Sun in orbits between those of Mars and Jupiter.

Under this hypothesis only can, I think, the remarkably sudden appearance of so bright and large a body be rationally explained.

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* Communicated by the author.

The result of such a collision, even at a quite moderate relative linear velocity, would be, obviously to heat the colliding bodies so that they would be disintegrated, and dissipated in the gaseous form, or as vapors and mixed dust and gases. Spectroscopic observations of this body seem to indicate that it shines principally, if not wholly by reflected light, and that therefore it must be composed of solid particles, probably greatly comminuted. The diameter of the vaporous globe resulting from such a collision would rapidly increase, just as would that of a puff of smoke following the explosion of powder, and the augmentation of the diameter, and therefore of the apparent surface, would be accompanied by a diminution of brightness, the decrease being inversely as the square of the increase of diameter, according to well-known optical principles, the actual number of light-giving particles remaining constant while the area over which they are spread increases as the square of the diameter. The elliptic elements determined by Rev. Mr. Searle and by Dr. Kreutz might well belong to one of the members of the asteroid group, and I think that they are the approximate elements of a resultant body due to the collision of two asteroids on, or shortly before Nov. 6, 1892, when Holmes discovered the comet.

The eccentricity is somewhat greater than the greatest appertaining to any of the asteroids, but this greater eccentricity in the orbit of a body resultant upon such a collision is perfectly normal, the arrest of orbital motion of the components tending to cause the resultant body to fall more directly toward the Sun and therefore to describe an orbit around that body more eccentric than either of the orbits of the original bodies of which the resultant is composed.

I hope to be able to determine soon which members of the group of asteroids are the components of this comet, that is, if such components were known members of the asteroid system.

ST. PAUL, Minn., Dec. 24, 1892.

It is an interesting fact that several astronomers independent of each other have suggested the hypothesis of collision for the origin of the Holmes' comet. That such an origin, within the asteroid belt, should have been thought of is singular; if it should prove to be the true explanation of the origin, it will be considered by the friends of the meteoritic hypothesis as an important fact favoring Mr. Lockyer's theory. The strongest point of evidence suggesting this origin is the spectrum of the comet which shows that it shines by reflected light only, so far as known by observation up to the present time. If the comet continues bright enough this feature will be studied further diligently.

HOW THE EARTH IS MEASURED. *

PROFESSOR J. HOWARD GORE.

One of the most primitive ideas regarding the Earth represented it as an immense plain, or flat island, surrounded on all sides by an interminable ocean. This ocean in the minds of the Greeks was only a river, called Okeanos, and into this the Sun made each night a plunge, to arise in the morning on the opposite side of the Earth. At the extremities and borders were placed the "fortunate isles," or imaginary regions inhabited by giants, pigmies, and such mythical creatures as a vivid imagination could call into being. But when men began to have experience of the sea by navigation, the horizon always observed as circular led to the notion that the ocean was bounded, and the whole Earth came to be represented as a circle, beneath which were roots reaching downward without end.

The cooling of the Sun from his daily bath demanded some change in the material into which he plunged. And as he could not go down on one side and come up on the other without making the subterranean journey, some provision had to be make for his passage. It was easy to imagine a tunnel through which he could pass, but as soon as the progressive and retrograde movements in his places of setting and rising were recognized, it was necessary that the support of the Earth be honeycombed with passages. The Buddhist priests declared that the Sun passed between the pillars which supported the Earth. And no sooner did they find this theory acceptable than they applied it to their ends. For, said they, these columns are sustained by virtue of the sacrifices which were made to the Gods, and any indifference on the part of the worshippers might cause a collapse of the Earth.

The ancient Greenlanders affirmed that the Earth is upheld by pillars which are so consumed by time that they crack, thus quaking the Earth; and were it not for the incantations of the magicians, the Earth would long since have broken down. Thus we see a myth reaching

"From Greenland's icy mountains
To India's coral strand."

The Hindoos held the Earth to be hemispherical, and to be like a boat turned upside down upon the heads of four elephants,

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* Extract from "The Journal of the Franklin Institute," Nov. 1892.

which stood on the back of an immense tortoise. This support, like a superficial answer, was sufficient until some curious questioner insisted upon knowing upon what the tortoise rested. The answer, upon the universal ocean, was soon proffered and gladly accepted, until the application of the further test, on what does the ocean stand? The ultimatum was then reached; the theory so boldly advanced and so ingeniously sustained needed a foundation principle; this it received in a shape that stilled further doubts and strengthened the whole superstructure: What supports the ocean? Why, it goes all the way to the bottom. This form of reply did not disappear with those who first made it, nor has it found a place in earth theories alone. Almost every science has advanced its line of interrogation points until a final all-sufficient answer is given, or an accepted axiom quoted.

Anaximander, a philosopher of the sixth century before Christ represented the Earth as a cylinder, the upper face only being inhabited. By some process now not known he computed its proportions, and gave as the result that its height was one-third of its diameter, and that it floated freely in the center of the celestial vault. The doctrine of "sufficient reason" prevailed then, or was invented to fit this particular case, because when asked why this cylinder did not tip over, he replied that in the absence of a reason why it should tip in any one direction rather than in another, it did not tip at all, hence remaining in this state of helpless indecision. A fellow-philosopher, recognizing the importance of air in the economy of nature, supported the cylindrical Earth of Anaximander on compressed air, which, owing to the vague and apparently imponderable character of air, did not suggest the need of a resting place for this air cushion.

Aristotle relied more upon fancy than upon fact, and deduced conclusions from logic and the nature of things rather than from observation. He reasoned from what he deemed natural to what must be or is. In answer to the question, Is the Earth at rest? he replied, "The Earth is in repose, because we see it to be so and because it is necessary that it should be, since repose is natural to the Earth." He also affirmed that a circle is a perfect line, being uninterrupted and without ends; and, therefore, the stars, created by God to endure forever, must have an eternal motion, and being perfect creations they must move in the perfect line—the circle. The heavens, also, possessing this divine attribute of perpetuity, must move in a circle. Then, as a grand climax, he asserted that since in every revolving circle there is a point of absolute repose, the centre, the Earth, being at rest, must occupy this central point.

Strabo, the geographer, who made the first century of the present era illustrious by his maps, declared the Earth to be spherical, for in all his investigations and study regarding the travels of sailors and explorers he found no mention of the end of the Earth. To him it appeared central and motionless, and in his consistent ignorance he unyieldingly affirmed that the entire habitable globe was represented on his maps, and was in shape like a cloak 8,000 miles long and 3,600 miles in width, the greater dimension being from east to west; hence our term longitude for degrees counted in that direction.

Bede, known as the Venerable, who lived in the eighth century, regarded the Earth as formed upon the model of an egg. Being an element, it is placed in the middle of the universe as the yolk is in the middle of the egg; around it is the water, like the white surrounding the yolk; outside that is the air, like the membrane of the egg; and around all is the fire, which closes it in as does the shell. The Earth, being thus in the centre, receives every weight upon itself; and though by its nature it is cold and dry in its different parts, it acquires, accidentally, different qualities; for the portion which is exposed to the torrid action of the air is burned by the Sun, and is uninhabitable; its two extremities are too cold to be occupied, but the portion that lies in the temperate region is habitable. The ocean, which surrounds it by its waves as far as the horizon, divides it into two parts, the upper of which is inhabited by us, while the lower is inhabited by our antipodes; although not one of them can come to us, nor one of us go to them.

As in other theories, a support was needed. To meet this requirement Edrisi, an Arabian geographer, broached the idea that the egg-like Earth floats in the great ocean as in a basin.

Although we are told that Pythagoras and Thales taught that the Earth was spherical, we see that their teaching was without avail on this point for nine centuries, while the shape of the Earth was the play of many foolish fancies. Bede again rounded it off and gave to it the egg shape which it retained in the minds of men for 1,000 years. Many of these theories were so erroneous that they were in nowise links in a great chain which could bind all peoples into unanimity of belief. But while many were beating time without marching, others were making progress along hopeful lines.

Now that the development of ideas had carried men far enough to accept a spherical globe, it was only natural that speculations were rife as to its size, and it was equally natural that some one should come forward with a method for determining this magnitude; and while this method might in itself be inaccurate or unsatisfactory, yet it would serve as a quickening force in the elaboration of better and still better plans.

Before attempting to measure the entire Earth it was necessary that considerable success should have been met with in measuring limited portions of its surface. Just when this art was first practiced is hard to ascertain; probably when Joshua was sent to spy out the land, he had in view quantity as well as quality.

We are told by Herodotus that the credit of discovering geometry belongs to the Egyptians, who found need of its principles in the restoration of those boundaries of fields which were obliterated by the overflow of the Nile. He also gives us the method of procedure when the river god consumed portions of a man's landed possessions. "If the river carried away any portion of a man's lot, he appeared before the king and related what had happened, upon which the king sent persons to examine and determine by measurement the exact extent of the loss; and thenceforth only such rent was demanded of him as was proportionate to the reduced size of his land. From this practice, I think, geometry first became known in Egypt, whence it passed into Greece."

With the acceptance of the belief that the Earth was spherical came the notion that by finding the length of 1° on the Earth's surface a simple multiplication by 360 would give the entire circumference, and this circumference being the same for the same sphere the measurement of 1° would suffice for the determination of the size of the Earth.

Following out this idea, Eratosthenes communicated in 276 B. C. a value for the Earth's circumference, followed in 135 B. C. by Posidonius, as results of approximate measures and erroneous observations.

Just here we must take a long step chronologically but not geographically. The exact sciences ceased to be cultivated in Greece and Egypt. They slumbered for centuries and awakened in Arabia. When the Arabians adopted the Mohammedan religion they became ambitious for mastery not alone in the field of battle, but in the arts and sciences. They embraced, extended and utilized the knowledge they found during their occupation of Egypt. They preserved trigonometry from oblivion and handed it down to us in its present shape, while to them we are indebted for the beginning and early development of practical astronomy. The Arabians reached their zenith under Caliph Almamon. He was not only a scholar, but a patron of the sciences, and assembled about him the most learned men of that period, among whom were Acaresimi, Alfraganus and Albategni.

This wise caliph was the next to make a contribution to the world's knowledge of the size of the Earth. In 819 he imposed upon his astronomers the task of measuring a meridional arc on the plain of Singar by the Arabian Sea. They divided themselves into two parties, and starting from a given point, one party went north, measuring with wooden rods as they went, the other due south, likewise measuring as they went. Each party continued, the former until they reached a point where the altitude of the pole was just 1° higher than it was at the starting point, while the other did not stop until they found a place where the altitude had decreased by 1°. Thus we see both groups had gone just a degree. The northward party had measured fifty-six miles, the southward, fifty-six and two-thirds miles.

It is said that they repeated their measurements and obtained identically the same results. However, others affirm that, appreciating the impracticability of the successful discharge of their duties, they adopted the value given by Ptolemy, which is perhaps about the mean of the two just given.

The method here described possessed geodetic features far in advance of those employed by the Greek mathematicians, but we have no information regarding the way in which the altitude of the pole was determined. From a lack of exact data as to the length of their unit, we are unable to form any opinion as to the accuracy of their result.

For 700 years speculation slumbered, and investigation was ignored. A cloud of ignorance hung over the world like a pall, and the attainments of the earlier inhabitants did not even remain as a shadowy dream. The discovery of mathematical writings left in Spanish cloisters by their Moorish invaders awakened some interest in the study of the exact sciences, and from the oblivion of the dark ages arose, Phœnix-like, the genius of that grander culture then begun, now unfinished.

In the opinions of men the Earth was a plane, and again there was that painful, tedious uplifting of the benighted people to the realms of truth. Fortunately, the demonstrations were not left to the theorist alone; the science of navigation had by this time enabled men to venture beyond their littoral thoroughfares, and Magellan, circumnavigating the world in his three-years' voyage, placed beyond the confines of hypothesis the globular form of the Earth.

In the ignorance of methods of determining differences of longitude, it was impossible to ascertain the amplitude of an arc extending east and west. The determination of latitudes was an early art, but the measuring of an arc of meridian whose amplitude was, centuries ago, approximately ascertainable was limited to direct measurement.

Inasmuch as the task of finding a suitable stretch of country fulfilling the required conditions was difficult, the number of direct determinations were few, being restricted to Fernel, 1525, and Norwood, 1633.

THE PHYSICAL APPEARANCE OF HOLMES' COMET.

H. C. WILSON.

The following notes are compiled from the notes and sketches in my observing book. The observations were made with the 16-inch equatorial of Goodsell Observatory, power 150, and the 5-inch finder, power 30.

Nov. 11, 11^h—The comet is very bright, nearly round and nearly uniform in brightness, except that following the nucleus, in position angle 120°, there is a bright miniature tail as indicated in the sketch (Plate I, Fig. 1). Notwithstanding the brightness of the comet, the faint stars of 11 and 12 magnitude show vividly through it. The diameter of the nebulosity is about 6.5′.

Nov. 15, 9^h—A sketch indicates that the comet was a little larger but fainter than on Nov. 11. The lower right side of the head is extended slightly more than the upper portion.

Nov. 18, 10^h—Careful micrometer measures give the following results:

Position angle of the miniature tail following the nucleus 113.6°.

Diameter of the head at right angles to this tail and through the nucleus 11.7′.

Distance from nucleus to edge of nebulosity on the side opposite the little tail 4.3′.

The sketch indicates that the nebulosity extended about 7′ on the following side.

Nov. 22, 9^h—The bright portion following the nucleus is much enlarged. Position angle 122.9°. Length 15′. Radius of head in opposite direction 5′. Cross-section through nucleus at right angles to tail 13′. In all of the above observations the nucleus was quite definite and of about the tenth magnitude, with little condensation about it except on the following side.

Dec. 10, 8^h—The comet is very faint. The nucleus is hazy, about 12 magnitude with condensation of nebulosity about 1′ diameter surrounding it.

With the 16-inch it was quite difficult to find the boundaries of the faint nebulosity of the comet. It was about 20′ in width across the nucleus and a degree or more in length. The sketch (Plate I, Fig. 2) gives a fair idea of its shape and extent. The nebulosity was better seen in the five-inch finder than in the 16-inch. The comet was picked up before the observation with a pair of opera-glasses.

Dec. 16, 7^h—Comet very faint but large, slight condensation about the nucleus.

Dec. 23, 8^h—Comet very faint but easily seen in the finder (five-inch); about 15′ in diameter. With this instrument the nucleus could not be seen. In the 16-inch but little could be seen but the condensation about the nucleus, 1′ or less in diameter. When the light was turned off for some time I could trace the nebulosity to about 5′ on the preceding side of the nucleus and farther on the following side.

From these notes and others which have been printed in this journal it will be seen that the behavior of this comet has been quite different from that of others in receding from the Sun. It has expanded very greatly in size, and its brightness has diminished out of all proportion to the law of the inverse squares of the distances from the Sun and Earth. Its spectrum on Nov. 18 did not show the ordinary bands of a comet spectrum, but was continuous through a considerable portion of the green. This seems to indicate that this comet does not emit light of its own but shines by reflected sunlight only. The diminution of brightness is quite consistent with the enormous expansion of the nebulous matter. The apparent decrease in size during the last observations appears to be simply because the nebulosity has become too diffuse to be longer visible.

On the whole the appearance has been that of a mass of steam such as might result from an explosion, gradually diffusing and becoming invisible because of its tenuity. Judging from the faintness of the nucleus at our last observation, Dec. 23, it seems hardly possible that the comet can be followed much longer, even with the great telescopes.

ASTRO-PHYSICS.

SUN-SPOTS AND MAGNETIC PERTURBATIONS IN 1892.*

A. RICCO.

The United States Naval Observatory has sent to the Catania Observatory a reproduction of the curves of the photo-magnetographs which give the magnetic perturbations of 1892. I have deduced from it the epoch of maximum by taking into account the greatest deviation of the declination (D.) and the greatest variations of the horizontal component (H. F.) and vertical component (V. F.) of the intensity of terrestrial magnetism. But the determination of the time of this maximum is not very certain, since the perturbations consist of very extensive and very complicated oscillations, and, morever, the maxima of D. H. F., and V. F. do not always coincide. I have confined myself to giving the times of these maxima, and I have compared them with the calculated times of the passage of the principal spot at its least distance from the center of the solar disc, *i. e.*, over the central meridian. I have reduced the time of the 75th meridian W. of Greenwich, which has been adopted at the Washington Observatory, to Catania time, which I employ in my daily observations of solar phenomena.

Following is a brief description of the spots at the time of their passage over the central meridian of the Sun, and the corresponding magnetic perturbations; the oscillations are referred to the means and expressed in minutes for D. and in ten-thousandths of the C. G. S. unit for H. F. and V. F.

JANUARY 4, 2^h P M. Large spot, very active; there are other spots, but they are smaller and more distant from the center of the solar disc. JANUARY 6, 4^h A. M. Great oscillation of D. from $-48'$ to $+14'$; corresponding oscillations of H. F. from $+3$ to -16, and also of V. F., but in the opposite direction, from $+22$ to -13.

JANUARY 28, 3^h P. M. Large spot, and a few other small ones very distant from the center. JANUARY 28, NOON. Brief perturbations. Rapid oscillation of D. from $+23'$ to $-5'$, strong oscillations of H. F. from $+6$ to -7, depression of V. F. to -13.

FEBRUARY 2 TO 4. No important spot on the solar disc. FEBRUARY 2 TO 4. Four or five perturbations, not strong in D. feeble in H. F. and almost absent in V. F.

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* Communicated by the author.

FEBRUARY 12, 4^h A. M. Extraordinarily large spot, very active, with red flames in the nuclei; north of it is an important group of spots; near the east limb is another remarkable group. FEBRUARY 14, 1^h M. Extraordinary magnetic perturbation, lasting nearly 36^h; continual and strong oscillations of D. from $+28'$ to $-62'$, enormous vibrations of H. F. and V. F., both traces leaving the field; aurora borealis, and extraordinary electric earth-currents (according to Mr. Preece).

MARCH 1 TO 4. No spot near the center of the Sun; important group near the west limb. MARCH 1 TO 4. Six or seven perturbations, unimportant in D. feeble in H. F., very feeble in V. F.

MARCH 7. No spot near the center of the solar disc; the great spot of February has reappeared at the east limb. MARCH 7. Perturbations lasting for two days; sudden oscillation D. of from $-28'$ to $+20'$; curious movement of H. F. from 1 to -13.

MARCH 10, 2^h P. M. The great spot of February, reduced to smaller dimensions, is again at the central meridian; no other important spot near the center of the solar disc. MARCH 21, 11^h A. M. Very strong perturbation lasting 30^h, great oscillation of D. from $+44'$ to $-9'$; very strong decrease of H. F. from -3 to -17. V. F. not recorded.

APRIL 23, 8^h P. M. Active and important group of spots and pores; other equally important groups farther from the center.

APRIL 25, 11^h A. M. Steady increase of D. up to $+16'$ and finally a fall to $-25'$; remarkable oscillations of H. F. from $+7$ to -6 and of V. F. from -6 to $+4$.

APRIL 24, 4^h P. M. Active and important group; other groups farther from the center of the solar disc. APRIL 26, 1^h P. M. Strong perturbation lasting about twenty hours in continuation of the preceding; remarkable increase of D. from $-22'$ to $+24'$; great oscillations of H. F. between $+5$ and -20; very strong fall of V. F. from -6 to -24.

MAY 1 TO 2. No spot near the center of the solar disc; several groups near the limb. MAY 1 TO 2. Two or three remarkable perturbations of D. H. F. and V. F.

MAY 16, 5^h P. M. Very large spot, very complicated and exceedingly active, and other spots nearer the center of the solar disc. MAY 18, 6^h P. M. During 24^h great disturbance of D. between $+20'$ and $-22'$; strong and repeated oscillations of H. F. between -20 and $+18$ and of V. F. between -24 and $+10$.

The following table gives in an abridged form the numerical values deduced from the diagrams of the perturbations, and from calculation of the positions of the spots; the *deviations* are the amplitudes of the oscillations near the *maxima* of the perturbations. The diameter of the spots is expressed in terrestrial diameters. The retardation of the perturbations after the time of passage of the principal spot at its least distance from the center of the solar disc is given by the difference in time, and also by the arc of heliographic longitude which the spot has traversed beyond the central meridian at the time of maximum magnetic perturbation.

Time of Passage over Cen. Meridian	Principal Sun-spots.	Diameter.	Heliographic Latitude.	Time of Maximum.	Magnetic Perturbations.	Deviations.			Retardation of the Perturbations	
						D.	H. F.	V. F.	In time.	In arc.
			°			′			h	°
Jan. 4. 2 P.M.	Very large	4	+ 20	Jan. 6, 4 A.M.	Very large	42	0.0013	0.0035	38	25
Jan. 28. 3 P.M.	Large	3	— 16	Jan. 29, noon	Large	28	13	13	21	12
Feb. 2 to 4	None			Feb. 2 to 4	Small					
Feb. 12. 4 A.M.	Extraordinary	14	— 30	Feb. 14, 1 A.M.	Extraordinary	90	∞	∞	45	25
Mar. 1 to 5	None			Mar. 1 to 5	Medium					
Mar. 7. 2 A.M.	None			Mar. 7, 2 A.M.	Large	48	14			
Mar. 10. 2 P.M.	Extraordinary	6	— 29	Mar. 12, 11 A.M.	Very large	53	20		45	25
Apr. 23. 8 P.M.	Large	2½	+ 11	Apr. 25, 11 P.M.	Large	41	13	10	51	28
Apr. 24. 4 P.M.	Large	3	+ 16	Apr. 26, 1 P.M.	Large	46	25	18	45	25
May 1 to 2	None			May 1 to 2	Medium					
May 16. 5 P.M.	Extraordinary	5	— 16	May 18, 6 P.M.	Extraordinary	42	18	34	49	27

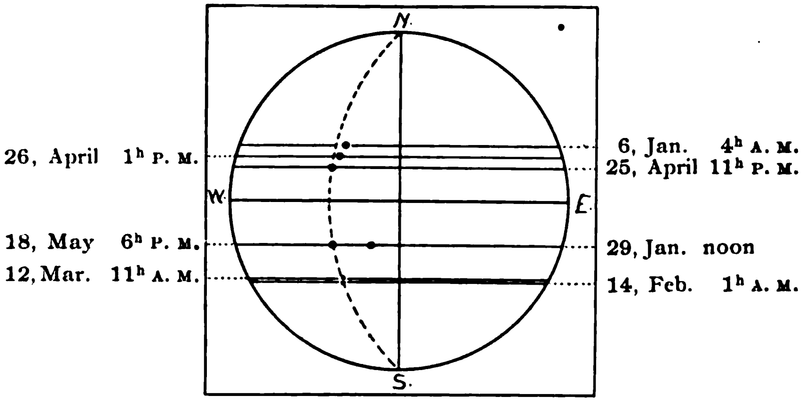
The schematic figure represents in an approximate manner the position of the principal spots at the time of the corresponding maximum; the heliographic latitude of the center of the solar disc, amounting to ± 7° 15′, and the resulting perspective curvature of the parallels, have been neglected.

It follows that out of 11 periods of perturbed terrestrial magnetism 7 occurred after the epoch of the passage of the principal spot over the central meridian at its least distance from the center of the disc, and that all perturbations, extraordinary, very strong, strong, have in general followed the same passage of spots respectively extraordinary, very large, large. Medium and feeble perturbations are produced without the passage of spots; so that there is a certain proportionality between the two classes of phenomena. The great perturbation of March 7 was the only one not preceded by the passage of an important spot near the center of the solar disc.

These retardations (except that of January 29) are comprised between 38^h and 51^h; the mean is $45\frac{1}{2}^h$; and as the synodic rotation of Sun-spots has a duration of about $27d = 648^h$, it is evident that this retardation is only about $\frac{1}{14}$, and the deviations from the mean which amount to as much as 7½^{h} are not at the most more than about $\frac{1}{100}$ of the time of this rotation period.

The figure shows the agreement of six cases, and evidently proves that it is not possible that this position of the principal spots (about 25° of heliographic longitude from the central meridian) can be the result of chance. It should also be added that two passages of the same extraordinary spot, in February and March, were followed after *the same retardation* by magnetic perturbations. At present it is impossible to explain the disaccord of the perturbation of January 29, which occurred only 21^{h} after the passage of the principal spot over the central meridian.

The retardation of 45½^{h} would indicate a velocity of propagation from the Sun to the Earth of about 913 kilometres per second for the action exercised by Sun-spots on terrestrial magnetism; this velocity would be more than 300 times less than that of light.



Positions of the Principal Spot on the Sun for Each Strong Magnetic Perturbation from January to May, 1892.

We certainly do not know whether the maximum of this action has its seat exactly in the nucleus of the principal spot of the group, as we have supposed and as seems probable; but in any case it seems very difficult to believe the seat of this action displaced more than twenty degrees of longitude behind the spots, where ordinarily only the secondary phenomena of pores and faculæ occur, these seeming by preference to *follow* the principal spot of the group. The retardation cannot, therefore, be explained in this manner.

It is known, especially as the result of the long and important investigations of M. Wolf of Zurich, that there is a perfect agreement between the mean variations of magnetic decliantion and the mean number of Sun-spots, and M. Garibaldi of Genoa has demonstrated that this agreement is verified even in the details of the variations. Father Secchi and M. Tacchini also admitted long ago a relation of spots and solar prominences with magnetic perturbations and auroras.

Lastly, observation has taught us that in Sun-spots there are great movements and contacts of various vapors at different temperatures, which might produce electric phenomena of great intensity. Moreover, it is known as the result of spectroscopic observation that many lines, especially those of iron, are widened in spots, which indicates a very great density, or at least a special condition of this metal in spots; and this may explain their magnetic action.

The ignorance in which we find ourselves as to the propagation of these electric or magnetic actions in a vacuum, or more exactly in interplanetary space, is not a sufficient reason for denying their existence.

It is my intention to pursue this inquiry for preceding years in order to see whether these relations between Sun-spots and magnetic perturbations always occur in the same manner.

OSSERVATORIO DI CATANIA, October, 1892.

ON AN ENORMOUS PROMINENCE, OBSERVED AT THE HAYNALD OBSERVATORY OCT. 3, 1892.*

J. FENYI.

On October 3, 2^h P. M. Kalocsa M. T. (or Oct. 2, 19^h Washington M. T.) I observed on the eastern limb of the Sun a prominence of perhaps greater dimensions than any previously measured, even at the period of maximum solar activity.

The phenomenon extended over 30° on the Sun's limb, and attained a height of 8′ 51″, that is, 0.552 of the Sun's radius, or 51,600 geographical miles. The form of the gigantic prominence was sketched at the eye-piece between 1^h and 2^h, and is faithfully represented in the accompanying plate; it was composed of a number of fragments, some of which were very brilliant. The numbers represent the measured positions, counting from north through east. They give the heliographic position —13° 14′ to

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* Communicated by the author.

PLATE IV.

Prominence Observed at the Haynald Observatory,

October 3, 1892, 2h P. M., Kalocsa M. T. Height, 8′ 51″.

ASTRONOMY AND ASTRO-PHYSICS, NO. 111.

RESUME OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE THIRD QUARTER OF 1892.[*]

P. TACCHINI.

The season has been favorable, and the series is nearly continuous. The following are the results:

		Relative Frequency		Relative Size		
1892.	No. of Days of Observation.	of Spots.	of Days without Spots.	of Spots.	of Faculæ.	No. of groups per Day.
July	32	24.32	0.00	153.1	80.309	4.77
August	30	21.20	0.00	123.83	57.17	6.50
September	27	19.22	0.00	72.82	86.40	5.37

The phenomenon of Sun-spots has thus continued with an intensity nearly as great as in the preceding quarter, although a slight progressive diminution is shown in the number of spots; the mean number of groups is also a little smaller. The considerable size of spots during the month of July, when the mean number of groups shows a secondary minimum, should be noticed; this is principally due to the large spot group which was at the center of the solar disc on July 10, and which occupied one-third of the radius of the disc; and the still larger group, which arrived at the central meridian on July 31, and extended over two-thirds of the radius; both these groups were visible to the naked eye. The presence of these groups, however, did not cause perturbations in our magnetic instruments, and the only important magnetic perturbation observed by us occurred on July 16. I therefore think that I have always been right in affirming that perturbations of terrestrial magnetism are in closer relation with the phenomena of the chromosphere and solar atmosphere, and especially with electrical solar phenomena, which we observe under the form of filamentous prominences and very rapid motions, than with spots. But to reach a conclusive demonstration continuous observation of the limb and the disc will be necessary, and I expect much from Professor Hale's beautiful photographic investigations.

For the prominences we have obtained the following results:

		PROMINENCES.		
1892.	No. of Days of Observation.	Mean Number.	Mean Height.	Mean Extent.
July	30	10.27	39″.2	1°.8
August	29	9.76	41 .6	2 .0
September	26	11.08	41 .8	2 .0

In the phenomenon of prominences we find a marked increase

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[*] Communicated by the author.

both in number and height as compared with the preceding quarter; for the spots the reverse was the case. In a few instances prominences have been seen at a great elevation above the solar limb, as in the case of the cloud observed by me August 1, which rose to a height of 364″.

ROME, Italy, Nov. 5, 1892.

THE MODERN SPECTROSCOPE.*

IV.

The Spectroscope of the Alleghany Observatory.

JAMES E. KEELER.

The spectroscope which is illustrated in the accompanying plates is the most important recent addition to the instrumental equipment of the Allegheny Observatory. Although not strictly a universal instrument, it is intended to be used for several different kinds of work, and to be efficient in all of them. In a previous article † I have stated the general principles which must be observed in constructing a spectroscope for any given purpose. It is not an easy task to design a spectroscope which shall satisfactorily meet a number of very different requirements, and in presenting the Allegheny spectroscope as one solution of this difficult problem, I wish to point out that some additions and conveniences, which might easily have been added, were rejected because it was thought that they might compromise the utility of the instrument in some one of its applications. After testing the spectroscope in both visual and photographic observations, although as yet only in a preliminary manner, there are very few changes that I should wish to make in the original design. The instrument is large and powerful enough to compare favorably with others of the highest class, designed for the same kinds of work, yet light enough to be readily mounted and dismounted, and to be carried by a telescope of moderate dimensions. It is convenient in use, and most important of all, it is very rigid, and capable of yielding results of extreme precision. The Observatory owes this splendid addition to its resources to Mrs. Wm. Thaw, of Pittsburgh, who generously supplied the funds for its construction without any limitations whatever. The spectroscope and all its accessories were made by Mr. J. A. Brashear. Hints for

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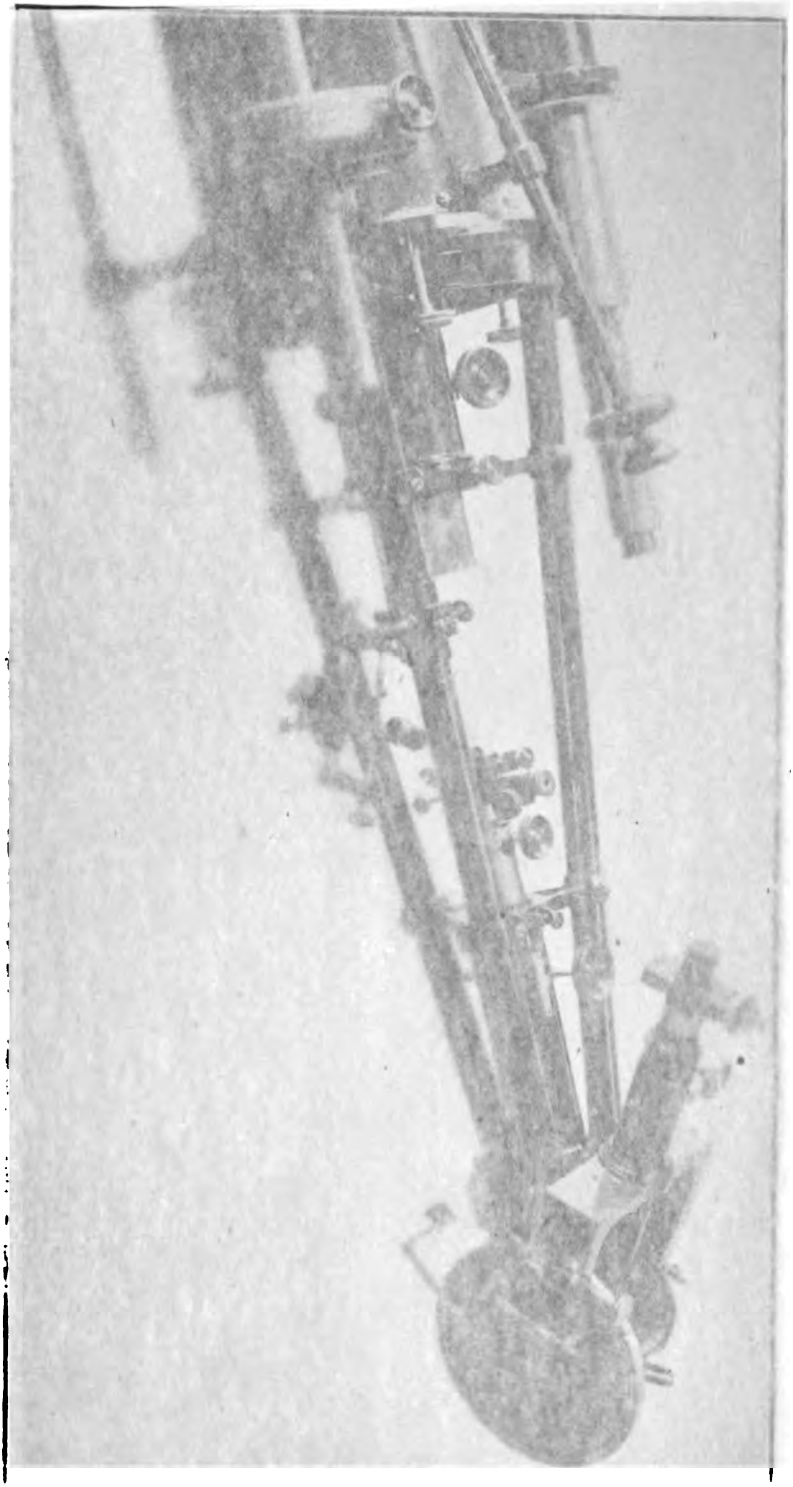
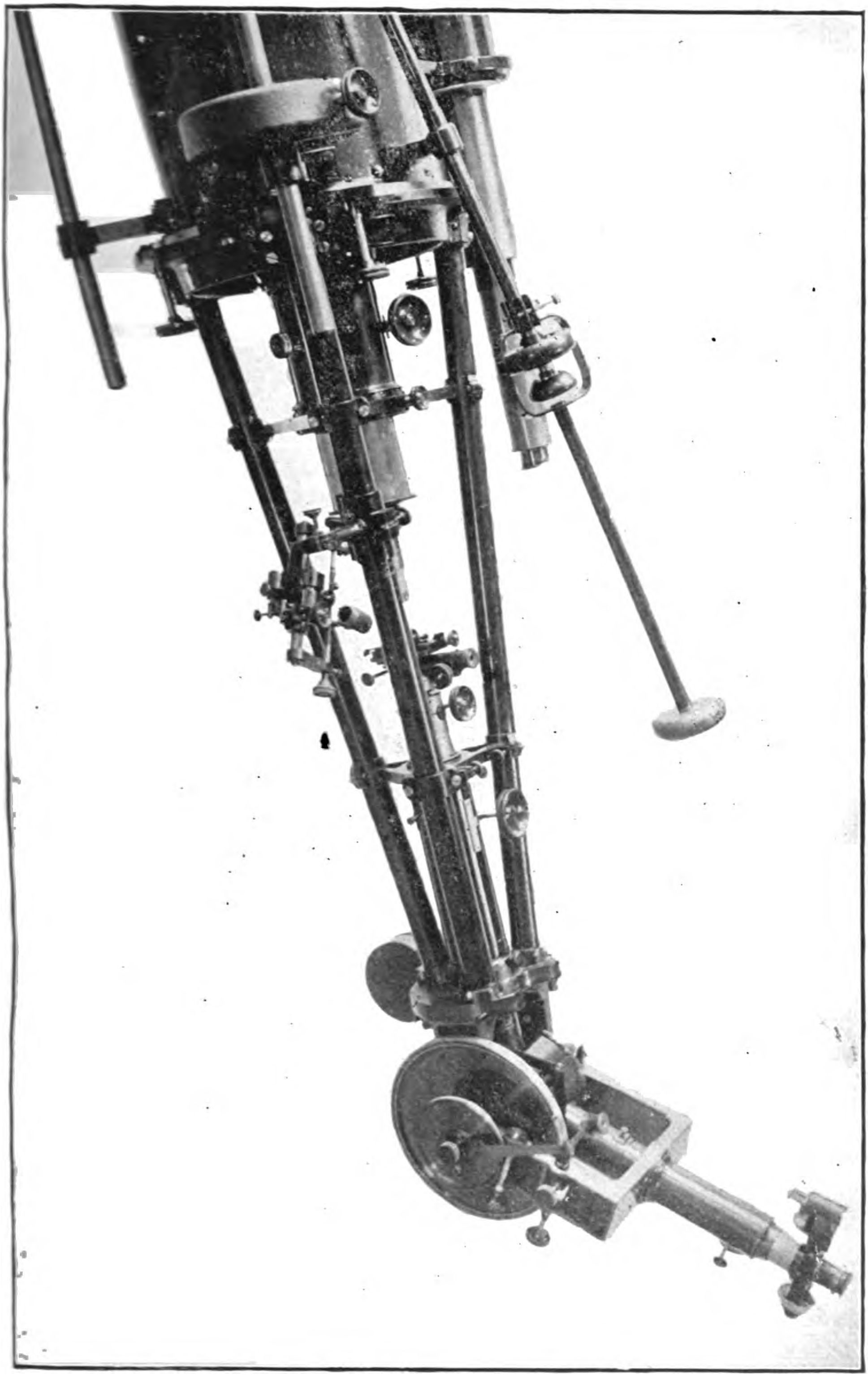
* Comunicated by the author.

† *Sidereal Messenger*, November, 1891.

PLATE V.





The Allegheny Observatory Spectroscope.

3. Arrangement [illegible] Single Prism for [illegible] [illegible]rvations.

PLATE V.

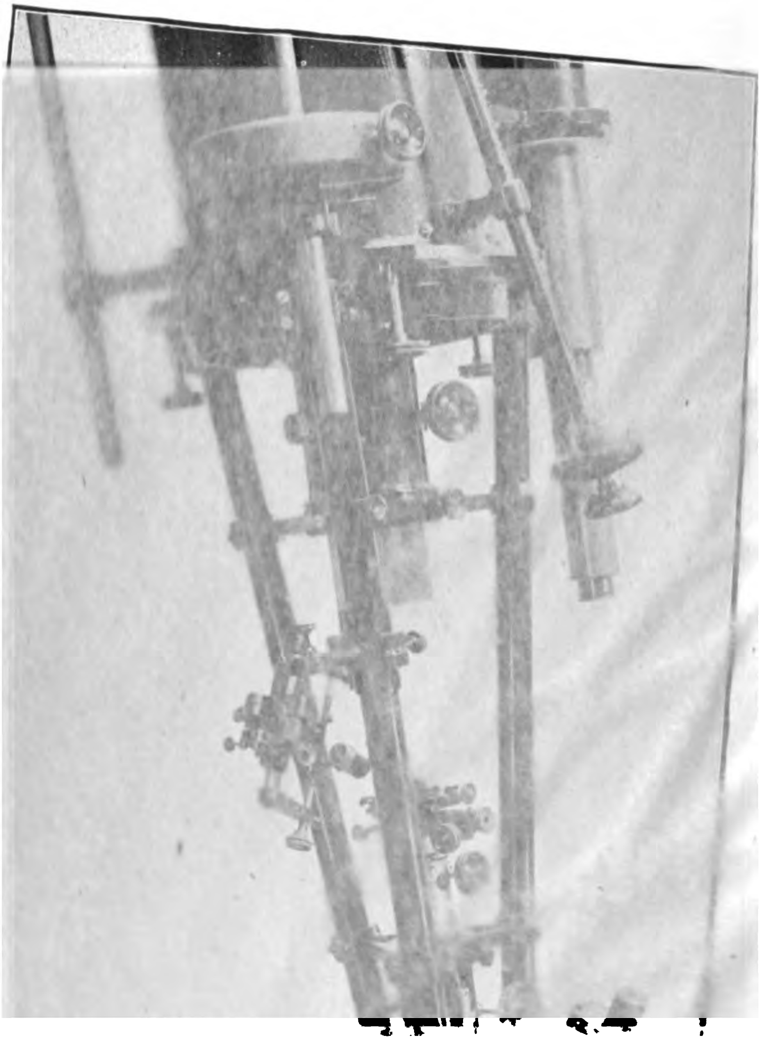
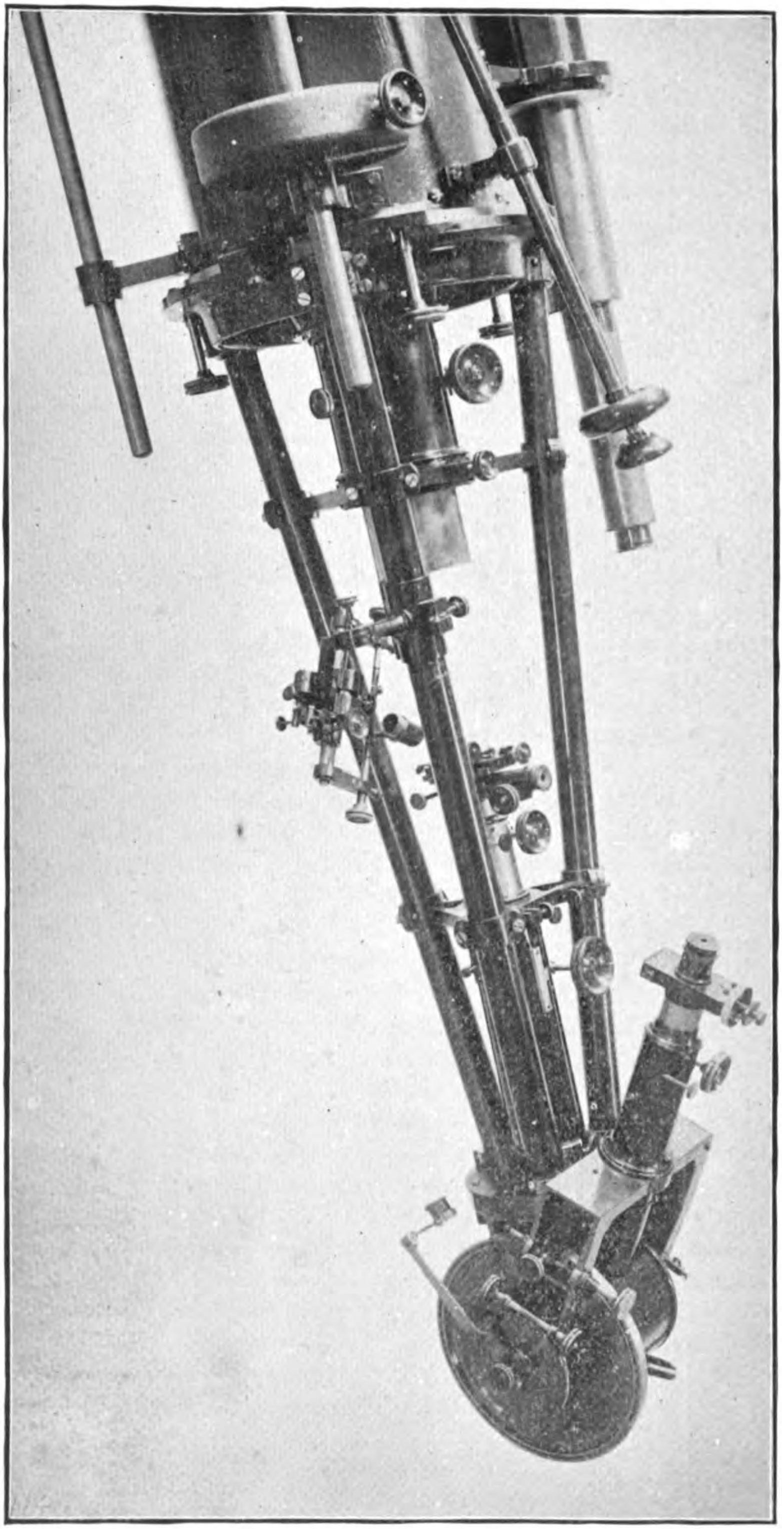


PLATE VI.

The Allegheny Observatory Spectroscope.

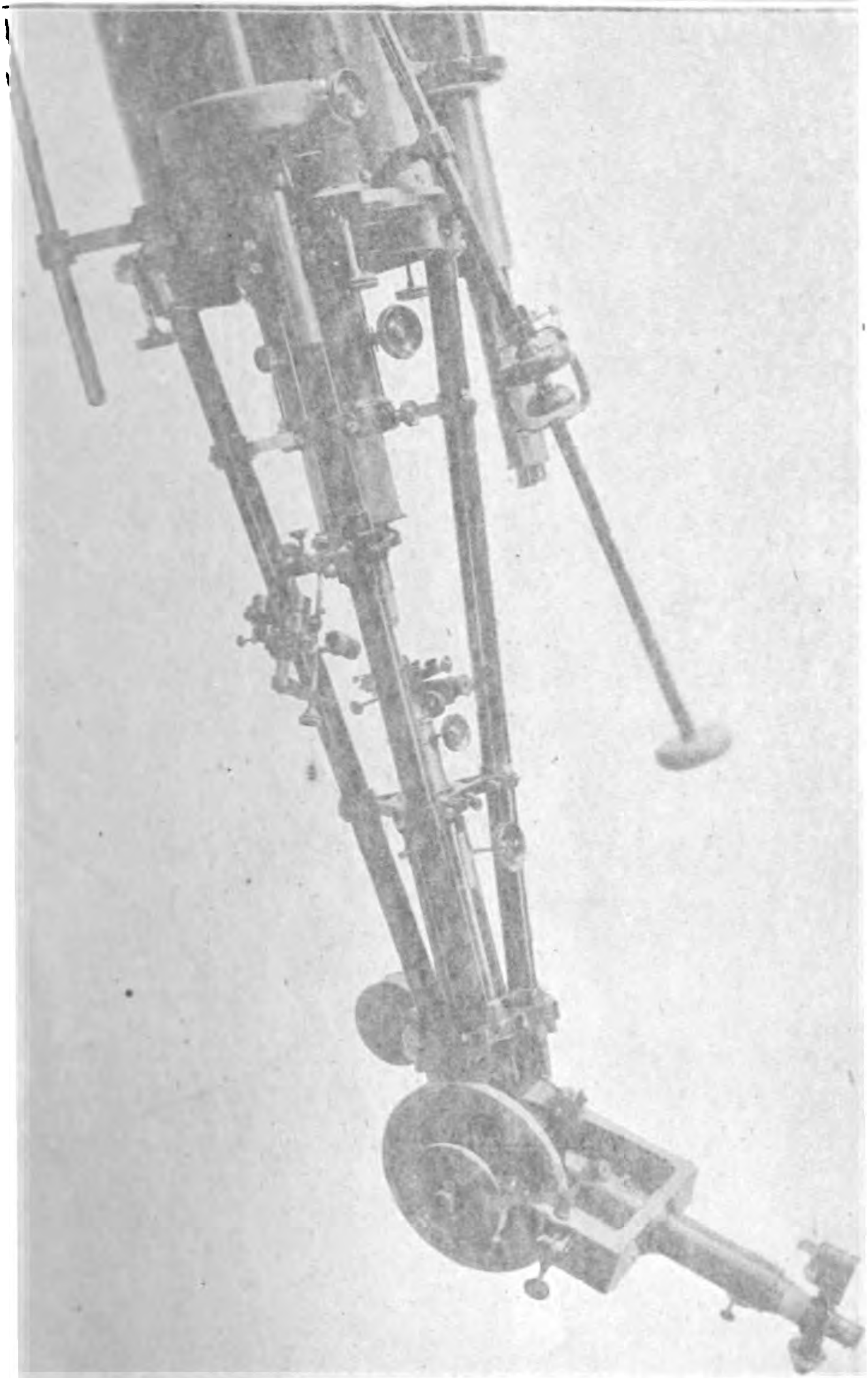
3. Arrangement with Single Prism for Visual Observations.



The Allegheny Observatory Spectroscope.

1. Arrangement with Grating for Visual Observations.

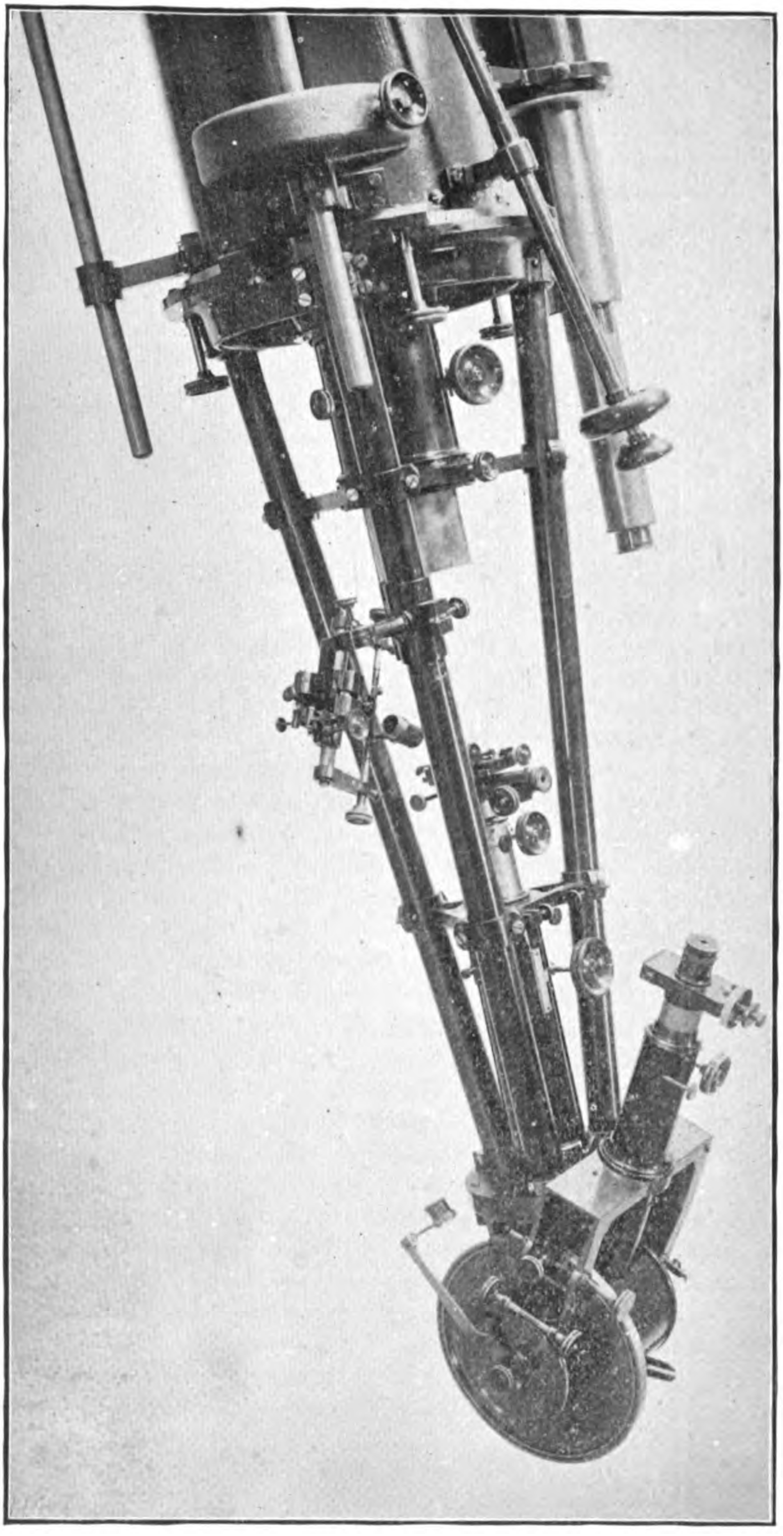
PLATE VI.



The Allegheny Observatory Spectroscope

Arrangement with [illegible] for Visual

PLATE V.



The Allegheny Observatory Spectroscope.

1. Arrangement with Grating for Visual Observations.

PLATE VI.

The Allegheny Observatory Spectroscope

B. Arrangement with [illegible] for Visual [illegible]

the design were gathered from various sources,—from my previous experience with the Lick Observatory spectroscope, from Vogel's spectrograph and other modern instruments, and from some very excellent spectroscopes which had been previously designed and made by Mr. Brashear. The working drawings were made by Mr. George Klages, foreman of the mechanical department in Mr. Brashear's works, and to his suggestions many practical improvements of the details are due.

The old wooden tube of the thirteen-inch equatorial did not promise to afford a sufficiently secure support for the spectroscope, and for this and other reasons it was replaced by a new steel tube, fitted with a new eye-end, finder, and other appointments. The end plate of the new tube is a strong casting, with a flange two inches greater in diameter than the end of the tube. This flange carries the entire weight of the spectroscope. The end plate is secured by nine pairs of butting and clamping screws, by means of which the axis of the tail-piece or collimator axis of the spectroscope can be accurately directed to the center of the telescope objective. The end plate is also provided with a position circle divided to degrees.

The main frame of the spectroscope consists principally of two rings, one large and one small, connected by three 1¼ inch steel tubes. The upper and larger ring is 13 inches in diameter. It forms the principal support of the spectroscope, and is clamped to the flange of the end plate by three stout screws, which are arranged as clips. When these screws are loosened the spectroscope can be rotated around the axis of the telescope, and the reading of the circle on the end plate gives the position angle of the slit. On throwing out the clips, the spectroscope is detached from the telescope.

A secondary support, which greatly increases the rigidity of the instrument, is formed by a smaller ring which fits accurately a slightly conical bearing on the lower end of the tail-piece. After the three large clamps have been tightened, this ring is also clamped, by a screw which is shown in the plates.

The lower ring is 6 inches in diameter. Its outer face is flat and smooth, with a depression for centering the attachments which will be described below. The hole in its center just allows the passage of the lower end of the collimator. An additional support to the rod is a triangular brace which holds the upper end of the collimator case. The collimator case has no centering screws, as the adjustment of its axis is effected by means of the screws in the end plate of the telescope, in the manner already described.

In constructing the instrument, the whole eye-end of the telescope was placed in a lathe, the spectroscope frame was built upon it, and everything was turned up true in this position, this method of construction ensuring the perfect centering of all the parts.

The face of the lower ring is 2 feet 7 inches from the end plate of the telescope, and 14¼ inches from the focal plane of the objective.

The collimator slide has a range of 1.4 inches. The position of the collimator is given by a millimetre scale and index on the outside of the case, the motion being effected by a large focusing head. The collimator tube, and all the sliding tubes of the spectroscope are nickel-plated. Two clamps secure the collimator in any desired position. A visual and a photographic objective are provided, each having a focal length of 16 inches and an aperture of 1¼ inch. As the ratio of focal length to aperture of the 13-inch refractor is 14.10, the effective aperture of the spectroscope is 1.13 inch. A stop with an aperture of this size can be placed on the end of the collimator, to limit the emergent beam from the comparison apparatus.

The slit is quite similar to the slit of the Lick Observatory spectroscope,* although a few additions have been made. The jaws open symmetrically from the center by turning a screw with divided head, one division of which changes the slit width by 0.001 inch. By turning another small head, the length of the slit can be varied. A thin tongue of brass, which is fined down to a point at its extremity, can be slipped over the exact center of the slit, in order that the comparison spectrum may be photographed without encroaching on the previously exposed photograph of a star spectrum. The width of the tongue at its intersection with the slit can be varied by a small adjusting screw. Another small head throws the 60° comparison prism on or off the slit. The diagonal eye-piece for viewing the slit from behind has a rack and pinion movement, and it is made to slide very easily between stops. When the train of prisms shown in Plate VII is used, this eye-piece is not accessible in its usual position, and it can therefore be rotated 90° and clamped in the position shown in the plate.

The tubes containing the cylindrical lenses fit the ordinary eye-piece adapter, and are adjusted to the proper distance from the slit by means of the focusing screw of the main draw-tube.

The comparison apparatus is quite similar to the same attach.

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* See ASTRONOMY AND ASTRO-PHYSICS, February, 1892.

ment of the Lick Observatory spectroscope, except that, as none of the rods is in the prolongation of the slit, it is secured to the frame of the instrument in a somewhat different manner. It is arranged for both metallic points and spectrum tubes, and all necessary adjustments are provided. An image of the source of light is formed on the slit, after reflection by the prism, by a lens which has a greater angular aperture than the collimator. The comparison apparatus can be readily detached from the rod which holds it, and placed, if desired, above the spectroscope, with the tube or spark in the optical axis of the collimator. In my opinion the latter arrangement is not a desirable one, at least when the metallic spark is used.

The parts of the spectroscope so far described weigh 42 pounds. They are common to all the different arrangements of the instrument, three of which are represented in the plates. The desired arrangement for any kind of work is obtained, in the first place, by attaching to the face of the annular plate in which the frame of the spectroscope terminates, one or the other of two distinct pieces of apparatus, each of which is a complete spectroscope with the exception of a collimator; and in the second place, by using with either of these attachments either a visual telescope or a camera. The separate attachments I have called, for want of better names, the "grating head" and the "prism-train box," or "prism-box." Each has a strong circular base-plate, which fits the terminal plate of the spectroscope frame, the two plates being held firmly together by four stout screws. In order to facilitate the change of heads, the screw holes are slotted and counterbored, and the screws need never be entirely withdrawn. With this arrangement the exchange of heads is very easily effected.

The base plate of the grating head is cast in one piece with two strong, ribbed arms, which project from it about 5½ inches and carry the pivots of the observing telescope. The distance between the parallel inner faces of these arms is 4.4 inches. The cross-arm which carries the observing telescope is also strongly ribbed. On one side is the fixed graduated circle, 8 inches in diameter, the edge of which is divided on silver with a double set of graduations. The outer set shows the position of the observing telescope, the inner set the position of the grating or prism. The circle is fixed in such a position that the reading of the outer vernier is zero when the telescope is in line with the collimator; for any other position of the observing telescope the reading of this vernier gives directly the deviation of the observed ray. Both verniers read to 30″ with the aid of a small reading microscope, or easily, by estimation, to 15″. In designing the instrument it was intended that the circle should serve mainly as a finder, the comparison apparatus and micrometer being relied upon for exact results by differential measurements. The cross-arm which carries the observing telescope is provided with a slow-motion screw and clamp.

Through the hollow pivot on the side toward the graduated circle passes the long spindle of the grating table, or circular brass plate on which the grating and prisms are mounted. The outer end of the spindle is fitted with a clamp, ratched wheel and tangent screw, all of which are well shown in the plates. Just below the grating table, the inner end of the spindle is encircled by a collar, which carries the tail-piece of the minimum deviation apparatus, and which is clamped to the spindle after the prism is set to the position of minimum deviation for any spectral line.

Each prism has its separate mounting, which is readily secured to the grating table. The grating is mounted in the usual manner, with all necessary adjustments.

Two loosely fitting, thin brass covers, one for the grating, and one for either prism, exclude all stray light in observing. One short piece of tube projects from the cover and receives the lower end of the collimator; another short tube is attached at one end to a thin plate, bent to the curve of the cylindrical side of the cover, and at the other to the end of the observing telescope, where it is held in position by a small clamp. The cover is prevented from falling off by a small screw pin, which passes axially through the pivot on the side opposite to the graduated circle, and enters a central hole in the top of the cover. No resistance is therefore opposed to the motion of the observing telescope.

When the grating is used, the minimum-deviation arms are removed; the observing telescope is turned toward the collimator until its cross-arm rests against two stops provided for the purpose, and then clamped. Different parts of the spectrum are brought into the field by rotating the grating. The angle between the axis of the collimator and observing telescope in this position is 30°, which is the smallest angle allowed by the construction of apparatus.

Both prisms have refracting angles of 60°. One is made of heavy flint, the other of light flint glass. The flat Rowland grating has 14,438 lines to the inch, the ruled surface measuring 1.3 × 1.8 inches.

The aperture of the observing telescope is 1.25 inch and its focal length is 10 inches. All the objectives of the spectroscope are made of Jena glass, and have a considerably smaller chromatic aberration than the ordinary combination of crown and flint. The lenses are cemented with castor oil. For the sake of stiffness the tube of the observing telescope is quite large (1.85 in. diameter), and for the same reason and in order to make the instrument as compact as possible, the tube projects through the cross-arm into which it screws, the broad flange of its bearing being 3 inches from the object-glass end.

The micrometer has 50 threads to the inch. It carries a coarse and a fine wire, illuminated by a small electric lamp at one end. The lamp is enclosed in a small box or lantern, fitted with a revolving disc containing colored glasses, which can be removed from the micrometer when desired. The micrometer is divided on "zylonite" to 100 parts, whole revolutions being read on a dial outside the box. The draw-tube is graduated to millimetres, and provided with a focussing screw and clamp.

There are three achromatic eye-pieces, one having a power of 5.6, intended to give the maximum of brightness, one with power of 12.5 for general use, and one magnifying 25.0 diameters for solar and other work requiring a high power.

In observing with a prism, the observing telescope is counterpoised. The bearing of the counterpoise arm is independent of the pivot which is on the same side, in order to preserve the pivot from strain or unequal wear.

Plate V shows the spectroscope arranged for visual observations with the grating, and Plate VI, the arrangement when a prism is used. In the latter plate an extension rod is shown, clamped to the slow-motion screw which moves the telescope in declination. This screw is thus brought within easy reach of the observer at the eye-piece. The slow motion in right ascension is effected by means of cords. A triangular piece of sheet iron with a small central hole is supported by the three rods, just in front of the slit, to protect the instrument from the heat in observing the Sun.

The weight of the grating-head, without telescope or counterpoise, is 17 pounds.

The prism-train box is attached to the frame of the spectroscope in the same way as the grating head. It contains a train of three rather dense flint glass prisms, connected by an automatic minimum-deviation apparatus, the details of which were worked out by Mr. Klages. Considerable study has been given to this important part of the apparatus, particularly with a view to securing the rigidity which is essential in photographic work with long exposures. The minimum deviation of the Hγ line for each of the 60° prisms is 60° 18′, or for the whole train, 180° 54′. Light corresponding to this line is therefore sent back nearly in the direction from which it came, a condition which allows a construction extremely favorable to rigidity. At the same time the movable prisms are an unfavorable condition. As I disliked extremely the idea of confining work to one part of the spectrum, it was necessary in adhering to the original plan, which allowed a considerable range of motion, to arrange the prisms in such a manner that no shifting of their positions could occur during a long exposure. The arrangement which was finally adopted as a probable solution of the difficulty is the following: each prism is mounted on a table with three feet, which rest on the flat face of one side of the prism-box. To these feet the link-work or gearing of the automatic minimum-deviation apparatus is attached, with a slight amount of play. Opposite the center of each prism, a clamp passes through the other side of the prism-box, by which the feet of the prism are pressed firmly against their support. Hence, when these clamps are tightened, the prisms are held, not by the link-work of the minimum deviation apparatus, but by the sides of the box, just as they would have to be held if they were fixed.

The observing (or photographic) telescope screws into a peculiarly shaped box, the faces of which are planed flat and truly parallel, and made as broad and long as possible. This box fits snugly and yet moves smoothly between the sides of the prism-box. Four clamps, two on each side, pass through curved guiding slots in the sides of the prism-box, and keep the observing telescope pointed in the direction of the emergent rays. The curvature of these slots was determined graphically. To this sliding box is attached the outer end of the minimum deviation train, which is of the geared form devised (I think) by Grubb. When all the clamps are tightened, the observing telescope and all the prisms are secured firmly to the sides of the prism-box. No slow motion is provided for the telescope with the train of prisms, as its position is not supposed to be frequently altered.

Whether this arrangement will give the desired rigidity with movable prisms, can probably be determined only by prolonged trial. I can only say that in a number of long-exposure photographs of planetary spectra, made with this apparatus, the lines are beautifully sharp, and show no traces of shifting of the prisms.

The camera, or photographic telescope, has an aperture of 1.25 inch, and a focal length of 16 inches. Both this, and the photographic collimator objective, are corrected for the Hγ line. The object-glass is adjustable by a focusing screw, the plate-holder remaining fixed. Its slide is provided with a scale, and a clamp not shown in the plate.

Two short rods extend from the frame of the spectroscope to a collar on the camera tube. When they are clamped to the latter the stiffness of the whole apparatus is greatly increased, as the slit and the camera are almost directly connected by a short brace. The range of the photographic telescope is from C to just below H.

The camera has two metallic plate-holders, for 2 in. × 3 in. dry plates, and a ground glass screen for approximate adjustment.

For exact determination of the photographic focus there is a separate attachment, consisting of metal plate, mounted in the same way as the ground glass, but having a central aperture, into which fits the high power eye-piece already mentioned. The inner face of the plate is made to occupy the exact position of the photographic plate when the plate-holder is inserted, and a spider line stretched across the aperture determines the plane of the plate in the field of the eye-piece. The focus of the different parts of the spectrum, or for the same part at different temperatures, may therefore, be found by visual observation of the lines in the solar spectrum. For monochromatic light there is of course no distinction between visual and photographic focus.

Both the camera and the visual telescope are fitted with "quartered" screws,* so that, when dropped into place, they are tightened by one-eighth of a turn.

For directing the telescope during an exposure, the method adopted at Potsdam has been followed. A small telescope, movable through a short arc, receives the light reflected from the first surface of the prism nearest to the collimator. After a few trials the straight tube at first used was cut in two, and a totally reflecting prism was inserted in a suitable mounting, the "broken" telescope thus formed allowing the observer to take a more comfortable position. A small incandescent electric lamp with a red glass bulb is inserted in the side of the collimator where it will throw light on the inside of the slit to illuminate the latter during exposure, so that it can be seen in the following telescope. I do not know whether this will prove to be a useful device or not.

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* Mr. Brashear suggests this name as preferable to the more common expression "mutilated" screw, used by artillery men and mechanics.

Plate VII represents the spectroscope arranged for photography of stellar spectra.

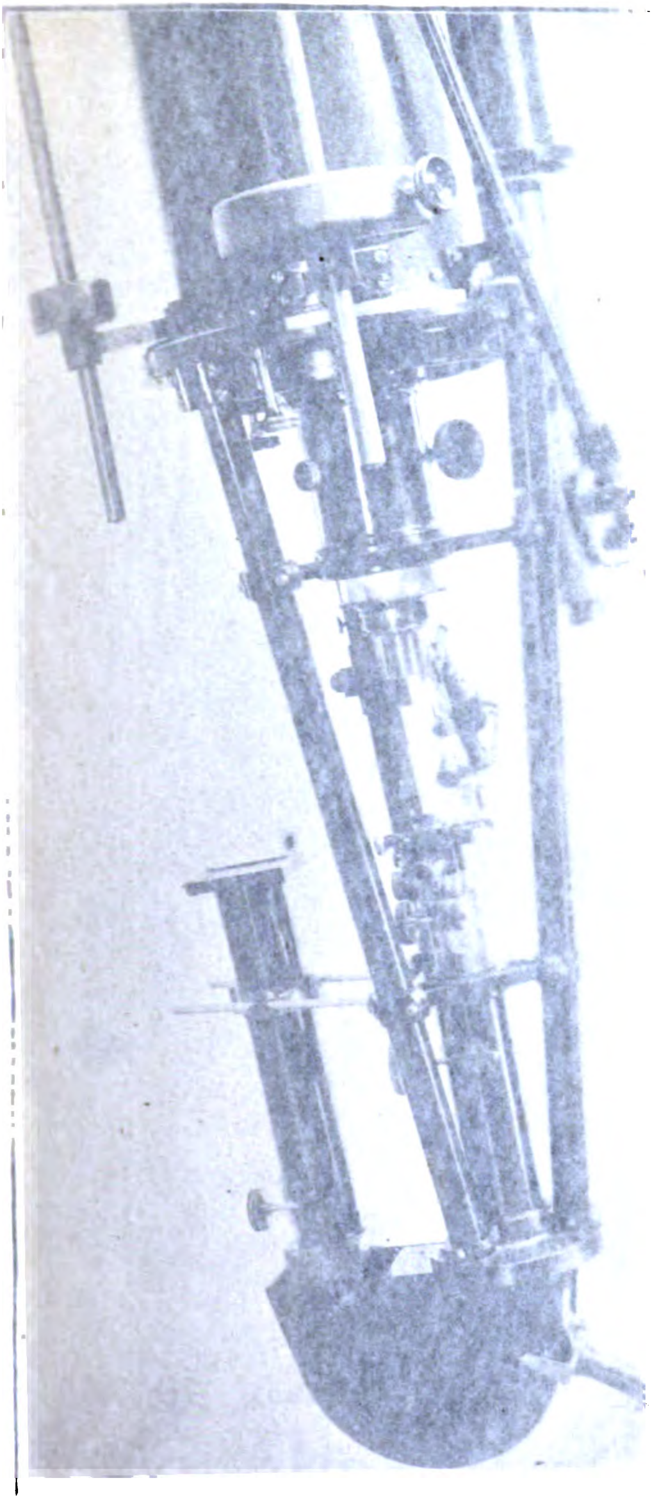
The weight of the prism-box, complete, without camera or observing telescope, is 12 pounds. The visual telescope weighs 2 pounds, and the camera with its side braces and plate-holder, weighs 4 pounds, 1 ounce. According to the arrangement of the apparatus the total weight of the spectroscope varies from 56 to 67 pounds.

To restore the balance of the main telescope when the spectroscope is removed, 100 pounds or less must be added to the eye-end, and for this purpose iron counterpoise weights are provided, as follows: four weights of 25 pounds each, two of 10 pounds each, and four of two pounds each. With these weights, which can be slipped along the telescope tube for a short distance, the spectroscope can be balanced with any desired arrangement. The rods to which the weights are secured are at such a distance from the tube that the balance in right ascension is never appreciably disturbed even when the whole spectroscope is removed, a point of considerable practical importance.

Preliminary trials have demonstrated the great convenience of this instrument in all kinds of spectroscopic work, and I cannot speak too highly of its mechanical execution. Optically, the most noteworthy feature is the use of simple prisms in the train for spectrum photography, instead of the compound prisms which have been so generally adopted of late. This was regarded as an experiment in designing the instrument, and after a number of trials I am still doubtful as to which method is the more advantageous. If the spectrum were intended to be viewed with an eye-piece, there is little doubt that the advantage would lie with the simple prisms as indicated by theory; but in photographic work the resolution of lines is limited in a less degree by the resolving power of the prisms than by the coarseness of grain of the photographic plate. Hence an instrument with moderate resolving power and considerable dispersion might be more efficient for photographic purposes than one with high resolving power and low dispersion.

In this connection a statement of some of the data regarding the construction of the prism train will be of interest. Each prism has a refracting angle of 60°, which, it may be noted, is very nearly the polarising angle for Hγ. The glass is dense and slightly yellow, but optical examination led me to think that the absorption of the upper end of the spectrum was not sensible as low as Hγ and above this line there was no occasion to work.

PLATE VII



The Allegheny Observatory Ser.

6. **Arrangement with Train of Prisms for Photographing Stellar Spectra.**

Astronomy and Astro-Physics, No. 111.

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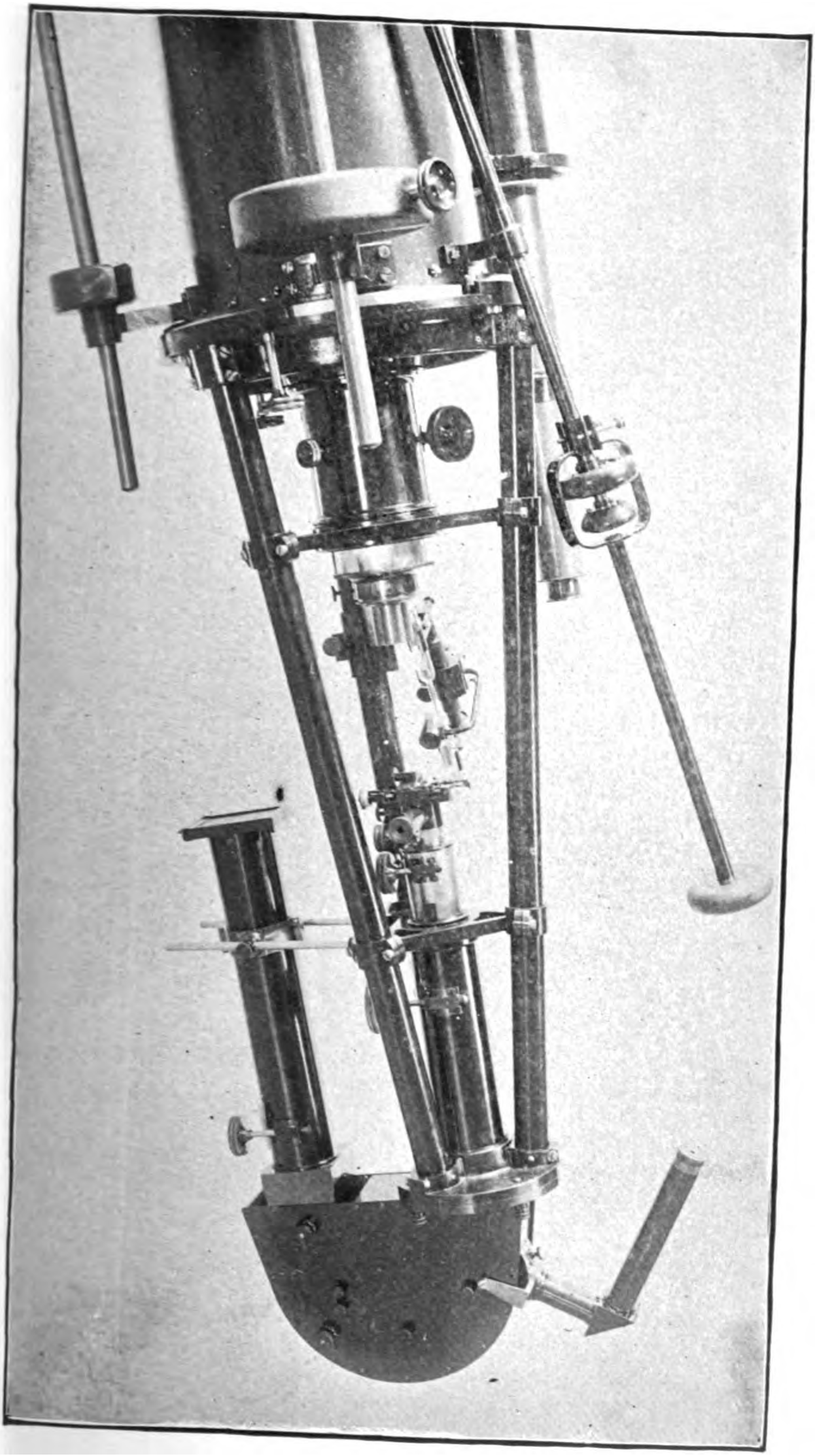

The Allegheny Observatory Spectroscope.

6. Arrangement with Train of Prisms for Photographing Stellar Spectra.

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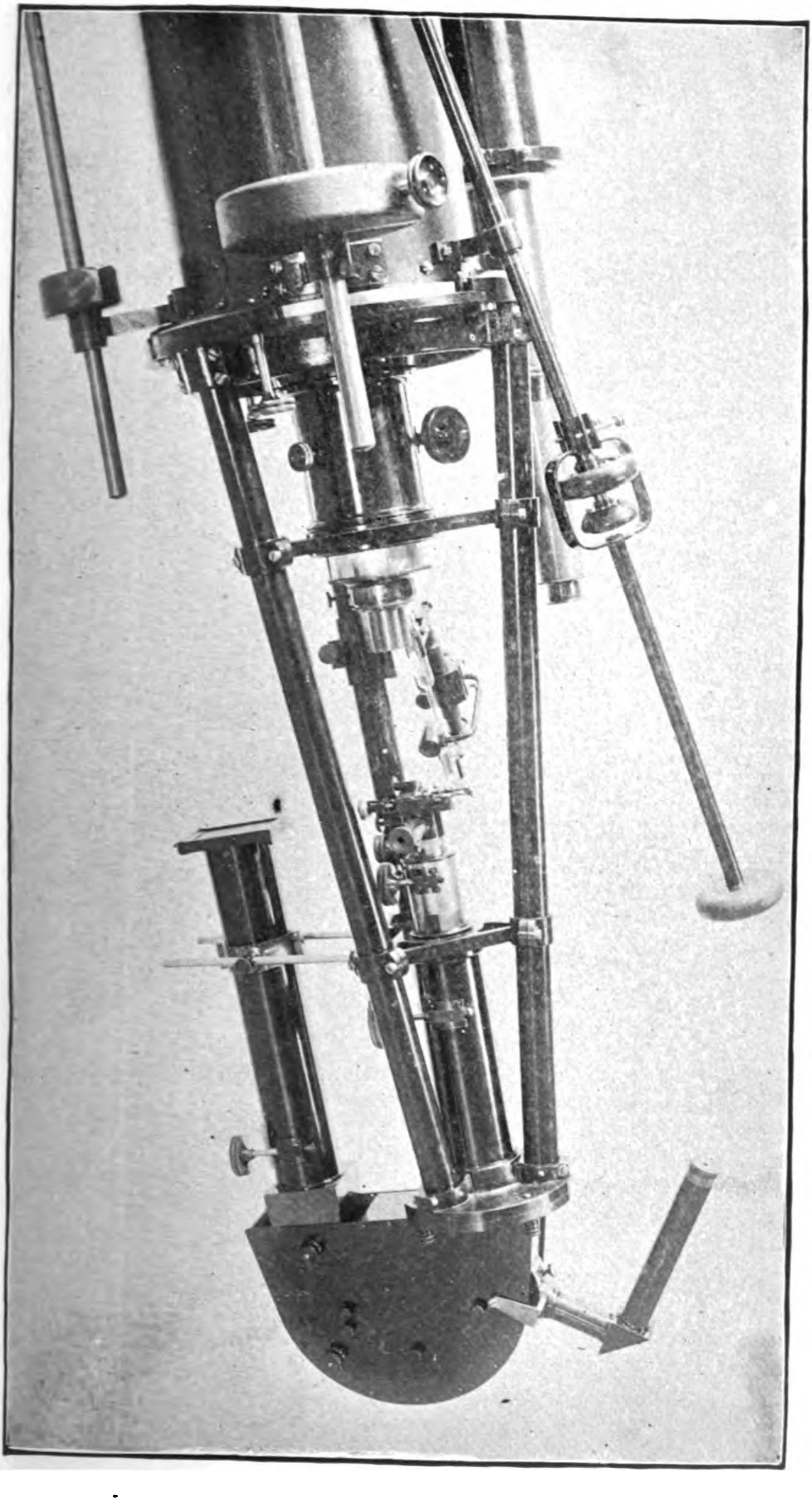
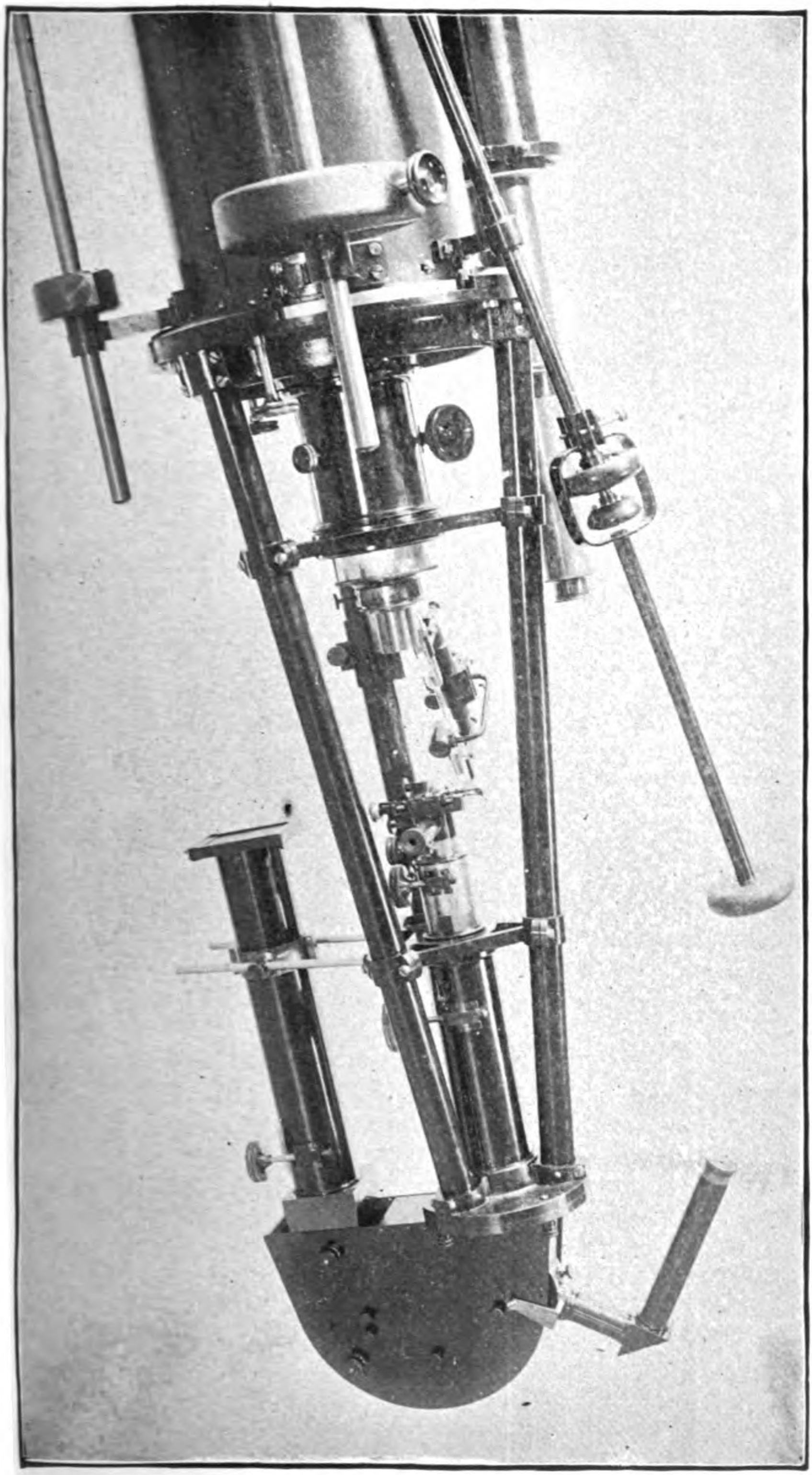


The Allegheny Observatory Spectroscope.

6. Arrangement with Train of Prisms for Photographing Stellar Spectra.

PLATE VII.



The Allegheny Observatory Spectroscope.

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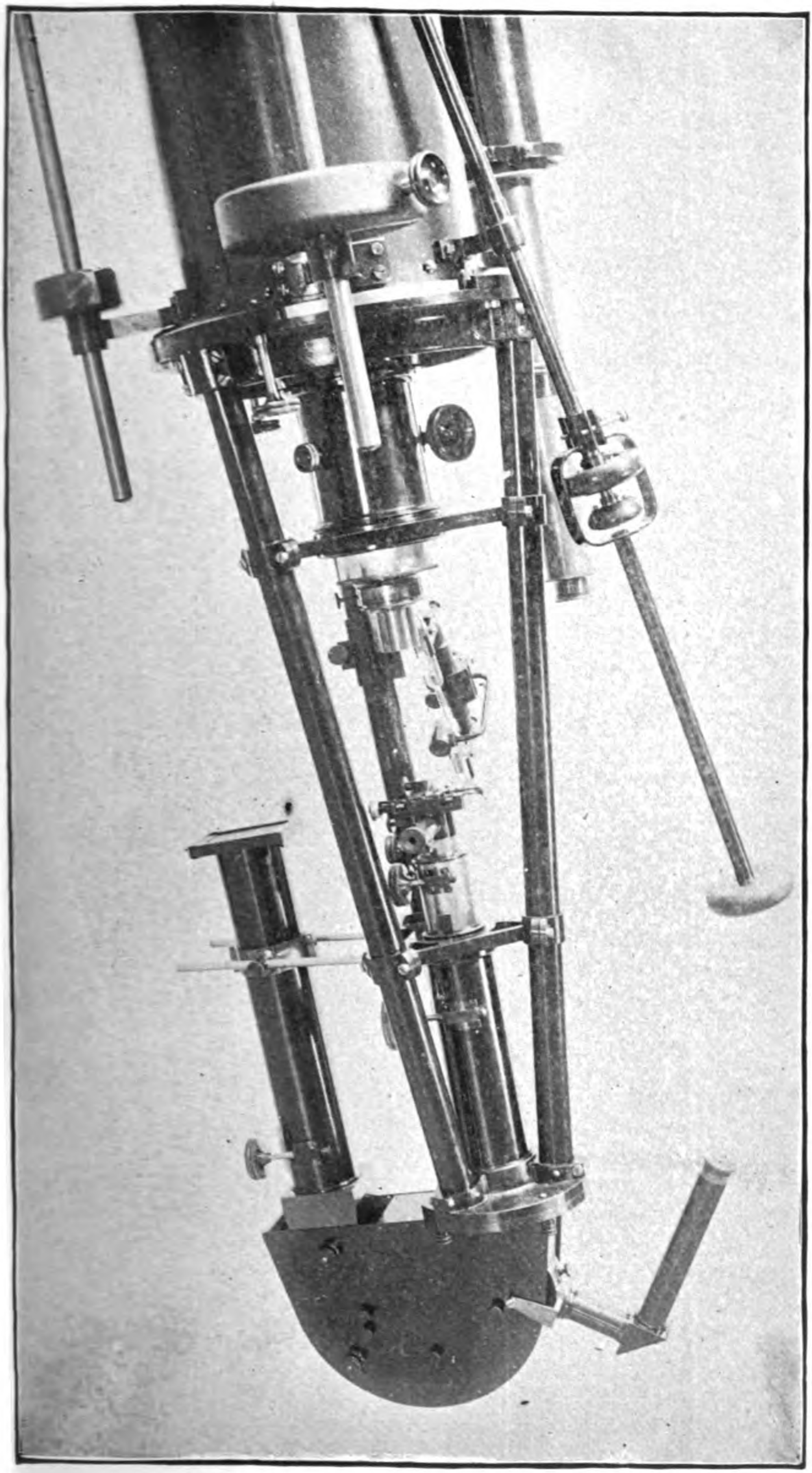

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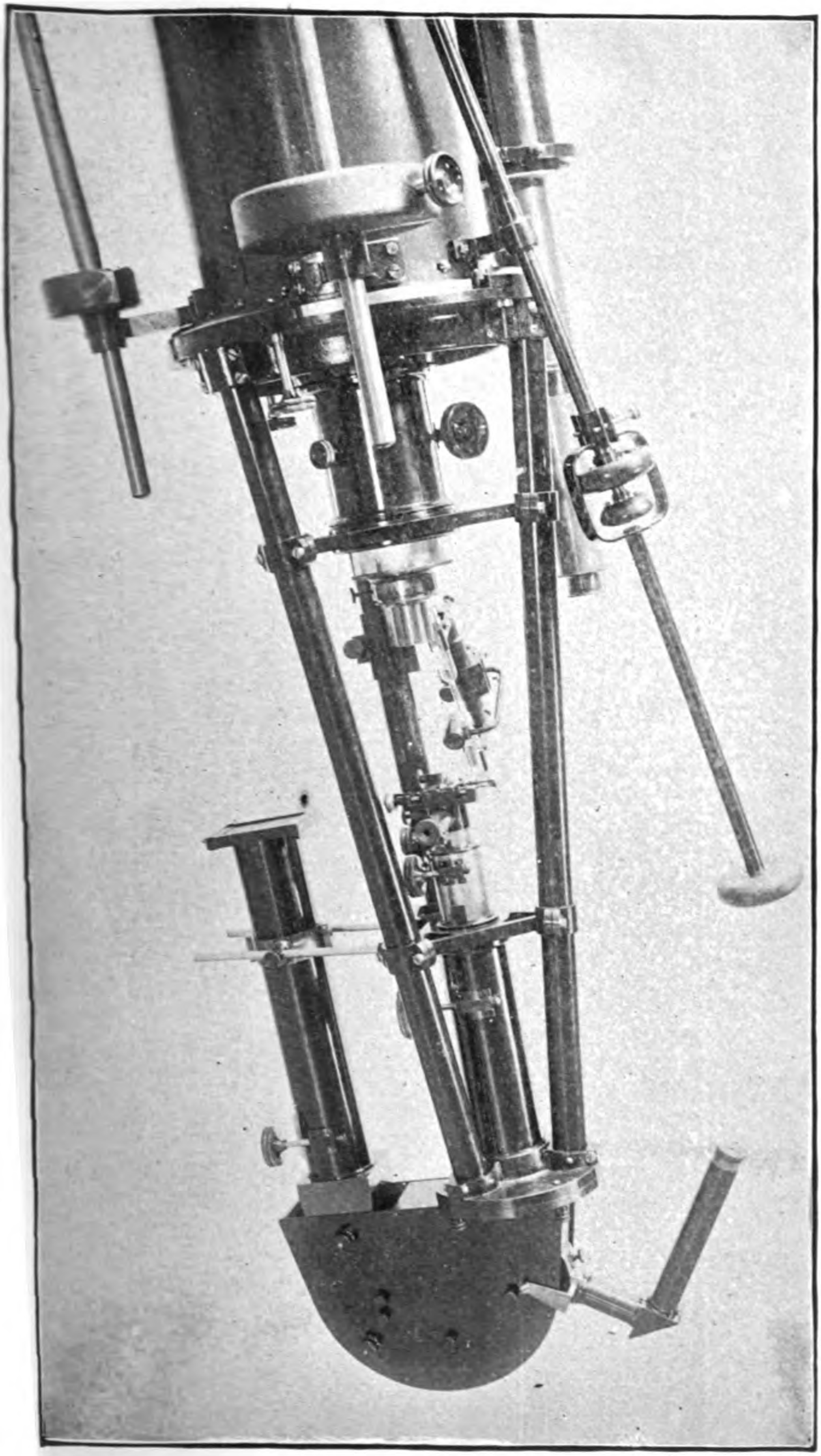

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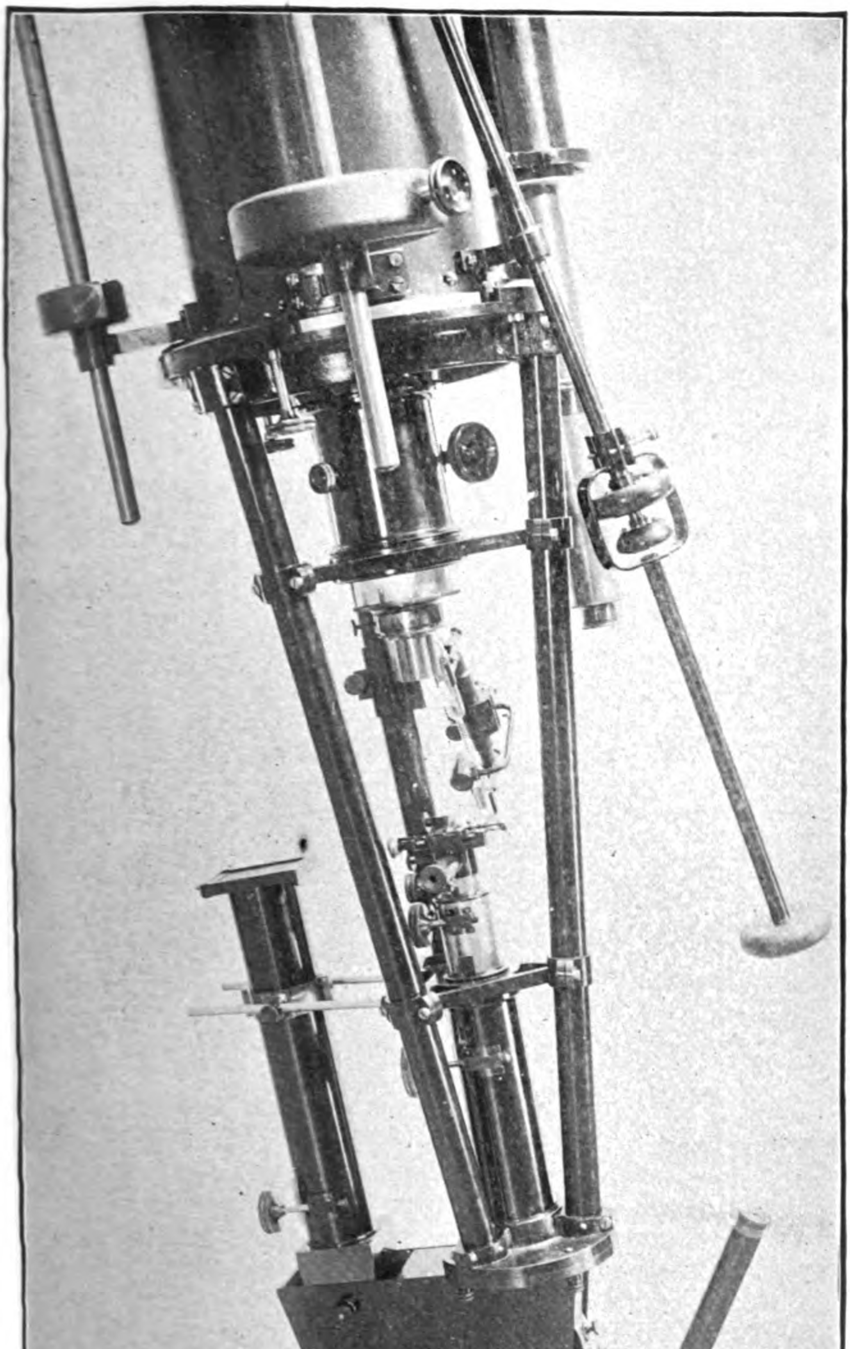

The Allegheny Observatory Spectroscope.

6. Arrangement with Train of Prisms for Photographing Stellar Spectra.

The approximate minimum deviations for some of the principal Fraunhofer lines are as follows:

B	55°	54′
C	56	8
D	56	51
b_1	57	58
F	58	41
Hγ	60	18
G	60	26
H	62	4
K	62	15

One millimetre on the photographic plate in the vicinity of the Hγ line = 12.5 tenth metres, the scale of the photographs being therefore slightly greater than that of photographs taken with the Potsdam spectrograph (1mm = 13.0 tenth-metres). With the high power eye-piece previously mentioned everything in Rowland's map can be seen in this part of the solar spectrum. The definition is superb. Considerably less detail appears in a number of photographs of the same region, but the four fine lines between λ 4337.2 and λ 4338.4 are separately shown, and the double line close to Hγ, at λ 4339.8, is divided.

On these plates the maximum photographic effect was considerably below Hγ, somewhere near λ 4500, and the darkening of the film fell off rather rapidly above Hγ to the upper limit of the plate. This position of the maximum might be due to,—(1), a real maximum sensitiveness of the plates used for a part of the spectrum below Hγ; (2), the rapidly increasing dispersion toward the violet end of the spectrum; (3), increasing absorption of the glass toward the violet. A photograph taken with the light flint single prism ruled out (1), and showed that the true cause was to be found in the combined effect of (2) and (3). I am still doubtful whether the absorption of the prisms has any considerable effect in reducing the brightness of the spectrum at the Hγ line. With a slit-width of 0.001 inch, an exposure to the Moon of five minutes gave a spectrum which was quite strong to the eye, but too weak and granular to bear much magnification The most suitable exposure for a measurable negative was from fifteen to thirty minutes. It might be more advantageous to use prisms of lighter flint, with somewhat greater refracting angles, and obtain the same linear scale of the photographs by increasing the focal length of the camera.

In general, this instrument is very nearly what I think a complete spectroscope for a telescope of moderate dimensions should be. To adapt it to larger telescopes, I do not see that any change should be made, except to increase the length of the collimator in order to keep the same effective aperture. The longer collimator would be required in this case because the ratio of focal length to aperture is usually greater for large than for small telescopes.

A duplicate of the Allegheny spectroscope has been ordered for the new U. S. Naval Observatory, and another will probably be made for the University of Chicago.

ON THE PROBABLE SPECTRUM OF SULPHUR.*

JOSEPH SWEETMAN AMES.

While pursuing in the winter of 1889 some investigations on the spectrum of hydrogen I was surprised to find on several of my photographic plates lines which evidently had no connection with hydrogen. These lines formed most beautiful series, bearing a striking resemblance to the B group of the solar spectrum. In some cases the series overlap, in others they are perfectly distinct. The head of each series is towards the shorter wave-lengths, and the lines are generally grouped in pairs. There is one very faint series of pairs beginning about wave-length 2860; at wave-length 3020 a series of single lines begins; from wave-length 3065 to wave-length 3200, there is almost hopeless confusion of overlapping series, most of the lines being strong and sharp; and at wave-length 3200 begins a series of at least 12 pairs, which in its intensity and in all its physical properties, is remarkably like the B group.

My reasons for believing these series to belong to the spectrum of sulphur are largely negative ones. The plates on which they appeared were taken consecutively on the same day. Since then I have tried to secure the same or similar conditions; but not once have I found a trace of the lines. I was using vacuum tubes containing large aluminium electrodes; and the hydrogen was admitted to the tubes over a mercury trap. Plugs of sulphur, blocked by glass wool, were interposed in the connecting tubes to stop the mercury vapor. It sometimes happened that the hydrogen would bubble up through the mercury trap faster than was desirable; and it is perfectly possible that with the mercury vapor, traces of which could always be detected in my tubes,

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* Communicated by the author.

some particles of sulphur were carried through. The only impurity detected in my tubes was mercury. Traces of water vapor always linger on the walls of vacuum tubes, but its spectrum is known. I have compared these new lines with all the spectra at my disposal, and can find no agreement. The fact that these lines form series so wonderfully like the B group, which is due to oxygen, is an argument, however faint, that they may belong to sulphur, since oxygen and sulphur are so closely connected chemically.

Being unable to convince myself that the spectrum which I obtained was really due to sulphur, I have never measured my plates carefully. I publish this note now only in the hope that some investigator may be able to succeed better than I in securing the necessary conditions for repeating my observation.

JOHNS HOPKINS UNIVERSITY,
Nov. 26, 1892.

STUDIES ON THE PHOTOGRAPHIC SPECTRUM OF THE PLANETARY NEBULÆ AND OF THE NEW STAR.*

EUGEN VON GOTHARD.

In the months of September and October I had, through the kindness of my friend, Dr. N. von Konkoly, the opportunity of taking some interesting photographs with an excellent objective prism of 10 inches aperture, which had been polished in the most perfect manner by Dr. Max Pauly, in Mühlberg, D. E. (Saxony). Herr Pauly, an exceedingly skillful amateur, has a passion for glass-grinding. He has done already several very good and large objectives, even of seven-inches aperture. I attached the prism to the upper end of my 10¼-inch reflector, and photographed the spectra with my ordinary star camera.

On the present occasion I will merely speak of my nebulæ-photographs in connection with my studies on the new star.

So far I have taken with the objective-prism seven planetary nebulæ, the Ring nebula in Lyra, and the Dumb-Bell nebula. The drawings represent the photographs on a larger scale. The wave-lengths are given in tabular form at the end of the article.

The photograph I took of the Dumb-Bell nebula shows its image as if no prism had been used. By measuring the nucleus from the hydrogen lines of the neighboring stars' spectra, I suc-

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* Translation by Miss Madelaine Fummel, communicated by the author.

ceeded in determining the wave-lengths of light, which the photograph had recorded. I found $\lambda = 372.4\ \mu\mu$ identical with the line which, in the large, irregular nebulæ, is always the brightest.

Gen. Cat. No. 4447. Ring nebula in Lyra. Sept. 17. Exposure 3 hours 30 minutes (Fig. 1). The spectrum consists of six rings, the first of which $\lambda = 502$ can also be seen with the spectroscope. It is considerably less elliptical than the others, which more or less encroach on each other. The last is the most intense, and a singularly true image of the nebula. I fancy I can see in the centre (though not with certainty) the little star, which I discovered in 1887 by the aid of photography.

Gen. Cat. No. 4964. Planetary nebula in Andromeda. September 25. Exposure one hour. (Fig. 2.) In a pretty large, continuous spectrum six knots of light are visible. The first, second and third are very intense. There also occurs a line which is absent in the Ring-nebula, at $\lambda = 470\ \mu\mu$, but the most intense line of the Ring-nebula is entirely absent. It is very strange that this line $\lambda = 372$, which is always very bright, almost the brightest in the larger nebulæ, should either be absent or very faint in the planetary nebulæ. The third line appears to be double.

Gen. Cat. 4373. Planetary nebula in Draco. Oct. 13. Exposure 70 minutes. (Fig. 3.) The continuous spectrum is considerably stronger and narrower, the knots are smaller and elongated, II is absent, VII present, very large and diffuse.

Gen. Cat. 4514. Planetary nebula in Cygnus. Oct. 14. Exposure one hour. (Fig. 4.) The continuous spectrum is much stronger, consequently the nebular lines are not very conspicuous; otherwise the spectrum agrees with that of 4373.

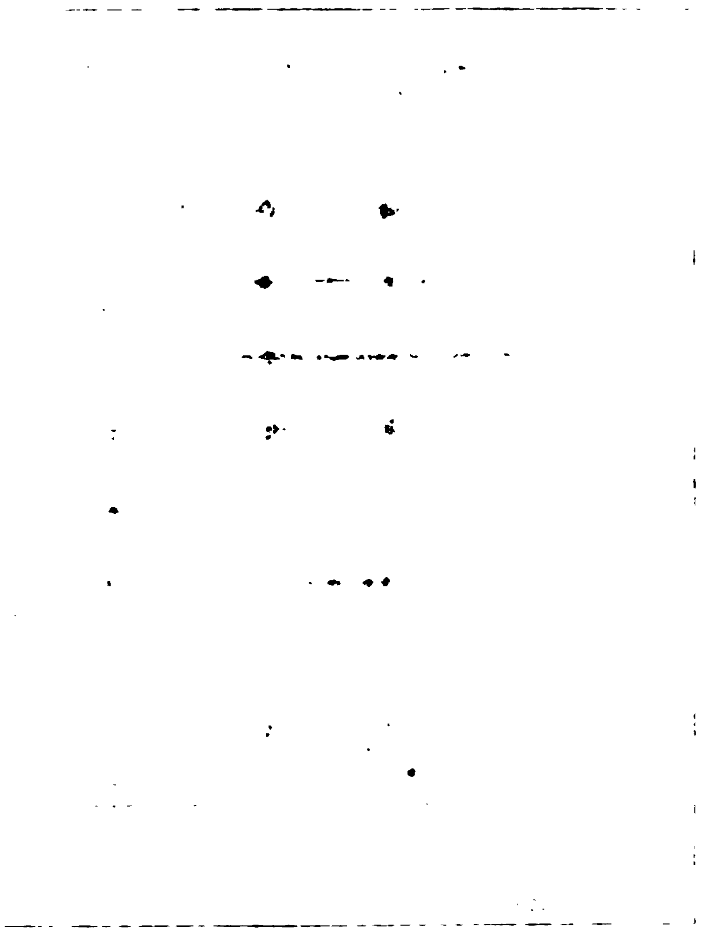
Gen. Cat. No. 4628. Planetary nebula in Aquarius. Oct. 27. Exposure one hour. (Fig. 5.) Almost identical with 4964, except that line VII is present. The continuous spectrum is not so broad, but the knots of light are larger.

New Gen. Cat. No. 7027. Webb's planetary nebula. Oct. 22. Exposure one hour. Magnitude 8.5. (Fig. 6.) The continuous spectrum is very fine, the knots small, III is especially intense, small, sharp.

New Gen. Cat. No. 6891. Copeland's planetary nebula. Magnitude 9.5. Oct. 27. Exposure one hour, thirty minutes. (Fig. 7.) The spectrum very much resembles that of G. C. 4514, the continuous spectrum being very strong.

New Gen. Cat. No. 6884. Copeland's planetary nebula. Oct. 28. Exposure two hours. (Fig. 8.) Spectrum very faint. Be-

PLATE VIII



Astronomy and Astro-Physics, No

[illegible]

[illegible] Cygnus. Oct. 24 [illegible]
[illegible] lines [illegible] very [illegible]
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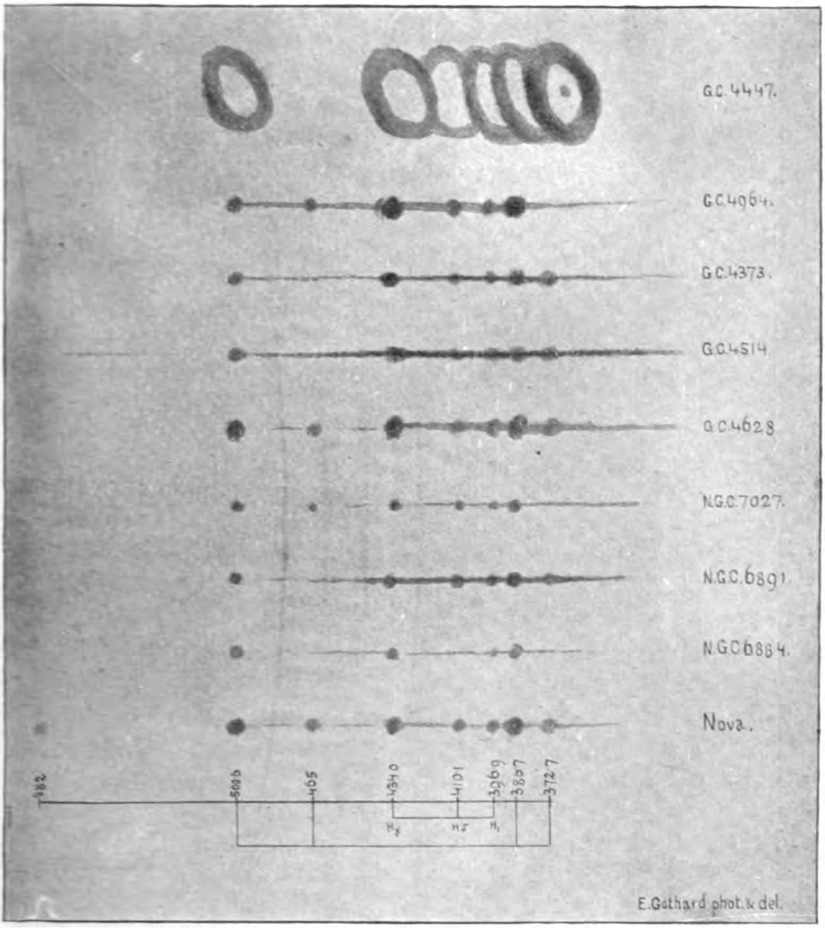
[illegible] larger

27 [illegible] Webb's planetary nebula [illegible] Oct. 22.
[illegible] magnitude 8.5 [illegible] (Fig. 6.) The continuous
[illegible] is small. [illegible] is especially intense

[illegible] Copeland's planetary nebula. Mag
[illegible] one hour, thirty minutes. The
[illegible] resembles that of G. C. 4. [illegible]
[illegible] strong.
6884 Copeland's planetary nebula [illegible]
[illegible] (Fig. 8.) Spectrum very faint. [illegible]

PLATE VIII.


G.C.4447.
G.C.4964.
G.C.4373.
G.C.4514.
G.C.4628.
N.G.C.7027.
N.G.C.6891.
N.G.C.6884.
Nova.
982
5006
465
4340
4101
3969
3867
372.7
H_γ
H_δ
H_ϵ
E.Gothard phot. & del.

[illegible]

[illegible] S[illegible] 17 [illegible] spectrum consists of [illegible] be seen [illegible] The [illegible] most [illegible] of the [illegible] centre [illegible] of photo[illegible]

[illegible] nebula [illegible] Sep[illegible] (Fig. 2 [illegible]) [illegible] of [illegible] The first [illegible] a line which [illegible] most intense [illegible] that [illegible] absent [illegible] faint in the [illegible] to [illegible].

G[illegible] 13. Exposure [illegible] 3.) [illegible] is [illegible] is considered [illegible] narrow [illegible] smaller and elong[illegible] present [illegible].

G[illegible] planetary [illegible] Cygnus [illegible] 14. Exposure [illegible] 4.). [illegible] nebula [illegible] [illegible]

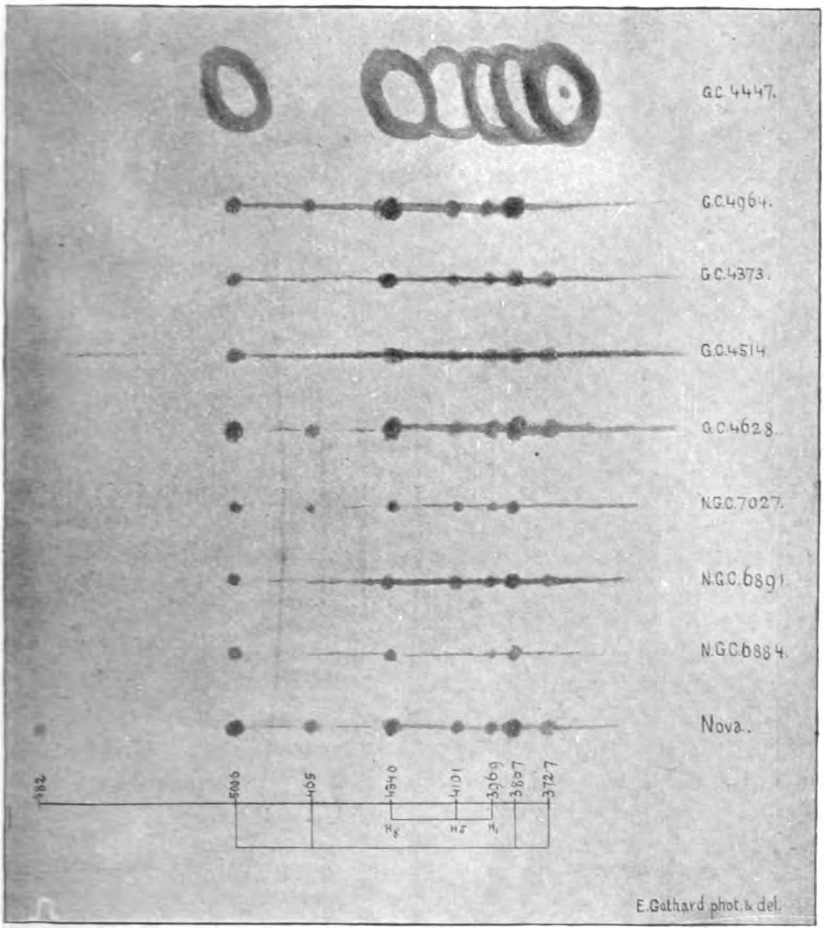
[illegible] Planetary Nebula in Aquarius. Oct. 27 [illegible] Fig. 5 [illegible] most intense [illegible] ex[illegible] present. [illegible] continuous spectrum is not se[illegible] [illegible]

[illegible] 27 [illegible]'s planetary nebula. Oct. 2[illegible] (Fig. 6.) The [illegible] small. H[illegible] is [illegible]

[illegible] 7 [illegible] Copeland's planetary nebula [illegible] one hour, thirty minutes. (Fig. 7.) [illegible] resembles that of G. C. [illegible] strong.

[illegible] Copeland's planetary nebula [illegible] 2[illegible] Exposure [illegible] Fig. 8.) Spectrum very faint [illegible]

PLATE VIII.



E. Gothard phot. & del.

sides the three brightest knots I, III, and VI, only V can be seen.

These photographs were taken with the objective-prism on Schleussner's orthochromatic plates. In order to determine the wave-lengths it proved necessary to take some of the brightest with the spectrograph, which, by using a slit, permits of photographing a comparison-spectrum. For this purpose I took with my quartz-Iceland-spar spectrograph the following nebulæ: Oct. 1, G. C. 4964, exposure 2 hours, 30 minutes; Oct. 29 and 30, No. 4628, exposure 5 hours; and on Oct. 10, the Orion nebula with an exposure of 2 hours, 30 minutes. The nebula and hydrogen spectra having been taken on one plate it was possible to identify the lines and to get a starting-point for determining the wave-lengths.

With a greater dispersion line III in No. 4964 appeared double, another faint line being found at $\lambda = 436$. I also measured a line before line VI at $\lambda = 388.9$ and another at $\lambda = 379.6$; both are hydrogen lines. No. 4628 much resembles it but is fainter, the nebula having been lower and the atmosphere very unfavorable. Thus three lines, which were measured in the other spectra, are absent. In reference to the Orion nebula I beg to state that an ordinary plate had been used instead of an orthochromatic one, for which reason the spectrum apparently begins at $H\beta$. Besides the nebular lines I obtained near nebular line VII a number of hydrogen lines.

The measurements are summarized in the table.

At the time I began my studies with the objective-prism, the new star in Auriga had again taken in the morning sky a favorable position for observation. Before describing my photographic results I beg to briefly communicate my observations made in the spring.

When the star was at its maximum brightness the spectrum consisted of a bright, continuous spectrum, reaching far into the ultra-violet. On its photograph from 40 to 43 bright and from 12 to 13 dark lines can be distinguished. The hydrogen lines as well as some others occur both bright and dark, the former very much displaced toward the red, the latter toward the violet end of the spectrum.

This beautiful spectrum, which I photographed six times and observed repeatedly with the eye, disappeared gradually with the brightness of the star. In the middle of March it was so faint that all further pursuit had to be abandoned.

In the autumn, on Sept. 15, I observed the spectrum for the first time with the objective-prism. It appeared among the numerous spectra of the neighboring stars like a somewhat greenish star of the 10th magnitude. By photography I obtained much handsomer, unexpected results.

As the spectrum taken on Sept. 15 could not be seen on the plate, I photographed it again on Sept. 19 with an exposure of 45 minutes. This time six spots of light were visible, which on renewed inspection could now also be detected on the first plate. A comparison with other photographs, especially with those of the planetary nebulæ, gave the surprising result that the spectrum of the new star perfectly agrees with that of the planetary nebulæ.

At first I thought it a mistake and took the region without the objective-prism. Comparing the photographs with former ones taken in the spring, the coincidence of the two photographs appeared so perfect as to exclude all doubts.

Further photographs taken on Sept. 27, with 2 hours, 15 minutes exposure, and Oct. 28, with 3 hours exposure, produced even more perfect pictures, which, compared with the above described spectra, give the highly interesting result, that the new star has changed into a planetary nebula.

The most beautiful spectrum, taken on Nov. 28, shows eight spots of light. The first is very faint and coincides with the brightest yellow line $\lambda = 582$ (after Vogel) of the Wolf-Rayet stars 4013 and 3956. The second is the chief nebular line $\lambda = 500.62$ (after Keeler). The next is again present in the Wolf-Rayet stars $\lambda = 465$ (according to my own measurements taken on the photographed spectra). The three following are hydrogen lines Hγ, Hδ and Hϵ. There are further present two more nebular lines $\lambda = 386.7$ and 372.7 (after my own measurements).

The difference in the wave-lengths appears insignificant upon the consideration that the measurements of the diffuse, somewhat elongated spots are very uncertain, and the entire length of the spectrum is but 3mm. Line Hδ shows the greatest difference; possibly another line is present there.

The results of the studies may be summarized as follows:

(1.) The spectra of the planetary nebulæ agree typically although they slightly differ in the intensities.

(2.) Hydrogen is represented in each spectrum by three or more lines.

(3.) Besides the hydrogen lines the presence of two characteristic nebular lines, $\lambda = 500.6$ and 386.7, can with certainty be proved in all, a third $\lambda = 372.7$ in most spectra. The fourth line $\lambda = 464$-470 seems to be less frequent.

(4.) Line $\lambda = 372.7$ which is always very intense in the large irregular nebulæ, is always very faint in the true planetary nebulæ, which fact marks a considerable difference between the two kinds.

(5.) In each spectrum can be detected a more or less developed continuous spectrum, corresponding to a nucleus or a condensation.

(6.) The physical and chemical state of the new star resembles at present that of the planetary nebulæ.

(A.) ***Table of Wave-Lengths of the Spectra photographed with the Objective Prism.***

				I.*	II.*	III.†	IV.†	V.†	VI.*	VII.*
1	G. C. No.	4447	—	502	—	434	411	396.5	386.5	373 μμ
2	"	4964	—	501	470	434	409	397	386.5	—
3	"	4373	—	502	—	434	410	396.5	386.5	373
4	"	4514	—	502	—	434	410	396.5	385.7	371
5	"	4628	—	501	468	434	408.5	396	386.5	372
6	N. G. C.	7027	—	500.7	464	434	410	395	385.7	—
7	"	6891	—	502	—	434	410	396	386.5	372
8	"	6884	—	500.5	—	434	—	395	386.5	—
9	New Star		582	500	464.2	434	407.7	395	385.5	372

* Nebular lines. † Hydrogen lines.

(B). ***Table of Wave-Lengths of Spectra taken with the Quartz-Iceland-Spar Spectrograph.***

	I.	1.	II.	2.	III.	IV.	V.	3.	VI.	4.	5.	6	VII.
Orion nebula...	*	486.1	...	...	434.0	410.1	396.9	388.9	386.7	383.3	379.6	375.7	372.7
G. C. 4964	500.8	...	469.0	436.0	434.0	410.1	396.9	388.9	386.8	...	379.6	...	—
G. C. 4628	500.9	...	...	...	434.0	410.1	396.0	388.8	386.7	...	...	...	—
Hydrogen lines	...	486.1	...	...	434.01	410.10	396.89	388.78	...	383.45	379.69	376.94	—

* Of the Orion nebula I. the chief line, is missing, an ordinary plate having been used, and not, as for all the others, an orthochromatic one.

My manuscript was already completed when I received the October number of ASTRONOMY AND ASTRO-PHYSICS. I have been much pleased in finding that the observations of Mr. W. W. Campbell of the Lick Observatory, substantially confirm my own, and that he also came to the conclusion that the spectrum of the new star is identical with that of the planetary nebulae.

I beg to briefly compare and discuss our respective observations made with very different instruments.

Mr. Campbell with the far greater aperture of his powerful 36-inch objective, was able to see the lines far better and more distinct; he even observed several times the duplicity of those lines which appeared to me to blend on account of the small size of the spectrum (the entire length of 580–373 being but 3 mm).

Naturally Mr. Campbell was able to determine the wave-lengths with greater accuracy.

	1	2	3	4	5	6	7	8	
Campbell	575	500.2	495.3	468.5	463.4	446.6	436.0	433.6	(Sept. 7.)
Gothard	580	500	—	464.2		—	—	434	(Oct. 28.)

1, 2 (4, 5) and 8 are identical with the lines I observed, 7 is present in the nebula G. C. 4964 ($\lambda = 436.0$); as for the others, I could find no trace of them on the plate.

Most probably I did not determine line I with sufficient accuracy, my scale being not reliable enough for this part, I inferred the wave-lengths from Vogel's observations of the Wolf-Rayet stars. Very striking and instructive are the considerable differences in the intensities of the single lines.

	1	2	3	4	5	6	7	8
Campbell	1	10	3	0.4		0.1	0.8	0.1
Gothard	1	8	—	4		—	—	10

No. 8, decidedly the hydrogen line Hγ, is, according to Mr. Campbell's measures, 100 times fainter than No. 2. From my own observations it is the most intense line of the entire spectrum. The solution of these differences is to be found, I think, in the different instruments employed.

Mr. Campbell works with a large glass objective of considerable thickness which entirely absorbs the refrangible rays of the spectrum. I am working with a silver-on-glass reflector with a crown-glass prism which at its thickest place is hardly 30 mm. Consequently, I am able to utilize those rays which can be photographed.

Mr. Campbell's observations have not only reassured me respecting the reliability of my results but they have also given me the satisfaction that my moderate sized instrument, with a rational utilization of photography, is capable of producing exceptional results not only in photographing very faint objects, as Professor Dr. H. C. Vogel, Director of the Potsdam Observatory, described in the *Astr. Nachr.*, No. 2854, but also regarding the spectroscopical study of extremely delicate objects such as the Nova, can compete with great refrctors.

It has always been a puzzle to me why this inestimable property of the reflector should not be more valued or used to better advantage.

Astro-Physical Observatory Hereny, Hungary.
Nov. 18, 1892.

THE SPECTRA OF HOLMES' AND BROOKS' COMETS (*f* AND *d*, 1892).*

W. W. CAMPBELL.

The spectrum of the very interesting comet discovered by Holmes is of an extreme type and probably unique. Visual observations made November 8 and 9 showed a continuous spectrum for all parts of the comet. It extended from near D to above G for the nucleus, for the very condensed and nearly circular coma (about 5′.5 in diameter), and for the very condensed tail seen within this coma. Outside the coma, in the direction of the tail, a very faint glow was just visible in the high-power finder of the spectroscope (which would probably be seen to better advantage under a low power).

This also gave a continuous spectrum, though very short, in the yellow and green. The position of maximum brightness in the spectrum was near λ 515, which doubtless was due to the presence of a slight trace of the usual green band. But except for the fact that the maximum brightness was higher than is generally the case in continuous spectra it would have escaped detection. The increased brightness was more noticeable in the spectrum of the very faint parts of the comet than in that of the bright parts. There was possibly a trace of the yellow band; but if so, it was exceedingly faint. Photographs of the spectrum extending from F to Hδ show it as continuous, but the wide slit required leaves it in doubt whether the Fraunhofer lines were present or not.

The spectrum of Brooks' Comet was (Nov. 9) of the usual type. The spectrum of the nucleus was continuous. The yellow and blue bands were poorly defined, but their lower edges were approximately at λ 561 and λ 472. The lower edge of the green band was sharp enough to measure with considerable accuracy, and was at λ 5152 ± 0.7.

MT. HAMILTON, Nov. 10, 1892.

ON THE DISTRIBUTION OF STELLAR TYPES IN SPACE.*

J. MACLAIR BORASTON.

Desiring to obtain a general view of the stars contained in the Draper Catalogue of Stellar Spectra in which the differences of spectrum and relative distribution as to type should readily

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* Communicated by the author.

appear, I constructed two series of charts upon an isographic projection, the first series containing all the stars of the D. C., numbering 10,351, and the second series only those stars the "observed brightness" of whose spectra did not fall below 6.25 on Professor Pickering's scale, which ranges from 4.0 (bright) to 8.0 (faint), the estimation being made for intensity of photographic action at or near the hydrogen line G. The number of stars contained in the expurgated series is 4334. I prepared this latter series that I might be able to work with confidence on the smaller number of stars, since, upon Professor Pickering's own admission, any spectrum fainter than 6.25 on the scale mentioned might fail to exhibit characteristics differentiating it from classes A, E and H, under which heads nearly all faint stars have been ranked.

To render the differences of spectrum apparent in the charts, I employed various colored inks, which, graduating down the spectrum from deep violet to red, might represent the gradation in the classes of spectra, from A, the first class of Type I to M, which includes the stars of Type III. I arranged that violet should be the fundamental color of the shades representing classes A, B, C and D constituting Type I, which are characterized in the case of Class A by a nearly continuous spectrum in which appears the series of absorption lines of hydrogen and the K line, the latter with varying intensity; and in the case of Class B, by the presence of the above and additional lines, the latter being most frequently 402.6 and 447.1. Classes C and D are numerically insignificant. The classes E to L mark varieties of Type II, the general features of which are that the brightest portions of the spectrum lie between K and F, the K line being nearly as strong as the H line, and the other lines faint.

When F, H and K only are visible, and no sudden change in intensity takes place, the star is placed under Class E. This class was represented by dark blue, and Class F, in which additional hydrogen lines are present, by light blue. Green was used for Class G, which is characterized by the presence of other lines in addition to those of Class F. A general property of Classes H, I and K is the greater intensity of rays exceeding λ 431 as compared with those of less wave-length. Under H is ranged the first-class so distinguished, I denotes additional lines, and K the presence of bright bands. L is numerically unimportant. Various tones of yellow and orange were employed to render these distinctions visible. M includes all stars of Type III in the spectrum of which a sudden change of intensity takes place at λ 476.2, rays of greater wave-length than this being fainter than those which are shorter. This class was represented by red, which closed the series.

It became evident in charting that stars having the most highly differentiated spectra were generally of the higher magnitudes, making it more than probable that the greater amount of light at command rendered visible those characteristics which entitled them to separate classification. It may therefore be concluded that the Classes A, E and H, under which headings are ranged the simplest and least developed spectra in their respective types and sub-types, include spectra of a higher degree of differentiation which, owing to deficient light, cannot be rendered evident. For this reason, when laying down curves to represent the relative numerical distribution of the various kinds of spectra, I gave one curve for Type I (Class A, B, C and D), a second for Classes E, F and G, a third for H, I, K and L, and a fourth for the latter two groups combined, which curve, therefore, represents Type II.

The curves were laid down for divisions of equal area, and in doing so, I followed Professor Pickering's divisions, in which zones are marked off by parallels at + 61° 2′.7, + 30°, 0°, and − 30°, the circumpolar zone being divided into three parts by meridians at 0^h, $VIII^h$ and XVI^h; the zone from + 61° 2′.7 to + 30° into nine divisions of 2^h 40^m each starting from 0^h; and the two equatorial zones into twelve sections respectively, also starting from 0^h, each section covering 2^h in R. A. There thus result 36 divisions of equal area, covering three-fourths of the sphere.

The curves were first laid down for all stars included in the D. C., then successively for those the inferior limit of whose observed brightness did not sink below 6.25, 5.75, and 5.25 respectively. At 5.25 the numbers of the spectra were too reduced to make it profitable to further extend the examination by this method.

It was found that the curve for Type I in the circumpolar zone was uniform for each of the four limits of observed brightness. In the division 0^h—$VIII^h$, it starts from a maximum of 20-30 per cent above average* in Cassiopeia and Camelus; in the second division $VIII^h$—XVI^h (Ursa Maj., and Min., and Draco) it falls to the minimum of about 30-35 per cent below average, and in the third division (Draco, Cepheus and Cassiopeia) XVI^h—$XXIV^h$, it re-ascends to an inferior maximum of about 15 per cent above average for spectra fainter than 6.25, those brighter

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* Average here and throughout the comparisons means the average per division for the group of spectra and the zone under discussion.

than this giving a curve coincident with average. The curve for 'all stars' Type II, in this zone is in marked contrast to that for Type I. Starting at 15 per cent below average in division 0^h—$VIII^h$, it reaches the absolute maximum for this zone in division $VIII^h$—XVI^h and declines to co-incidence with average at XVI^h—$XXIV^h$. The curve is thus strongly anticlinal to that for Type I in this zone.

The supremacy of the second type curve for 'all spectra' in the second division of this zone is due on the one hand to an assemblage of faint E, F and H stars in Draco and Ursa Minor, and on the other to a decline in the density of distribution of first type stars after V^h 30^m R. A., which do not resume anything like the compactness observable before this point until we reach $XVII^h$ 30^m R. A. on the opposite side of the sphere.

In the sets of curves for limits of observed brightness 6.25, 5.75 and 5.25, the elimination of these faint second type stars brings the curves below those of the first type stars, and they now pass up from somewhat below average in 0^h—$VIII^h$, without pronounced deviation in $VIII^h$—XVI^h, to the maximum for these curves of from 40-50 per cent above average in XVI^h—$XXIV^h$.

This maximum for the brighter spectra of second type stars in XVI^h — $XXIV^h$ is due to a rapid increase in number and magnitude of F, I and K stars in Draco and Cepheus.

The separate curves for E, F, G and H, I, K stars, which go to form the second type curve just treated of, exhibit both here and in all other zones, the most intimate sympathy, and their averages are practically equal.

The next set of curves represents the intermediate northern zone enclosed by the parallels + 61° 2'.7 and + 30°, which, as stated above, is divided into nine parts of 2^h 40^m each part.

In this set the first type curve for 'all stars' starts at once in 0^h — II^h 40^m (Cassiopeia, Andromeda and Perseus) with the absolute maximum for this zone of 85 per cent above average, sustained with an insignificant decline through II^h 40^m — V^h 20^m (Perseus and Auriga), after which it descends steeply for the extra galactic region to about 10 per cent below average in V^h 20^m — $VIII^h$ (Auriga, Lynx and Gemini), and continues an even downward course through Lynx, Ursa and Leo Minor, until it reaches its minimum 60 per cent below average between X^h 40^m — $XIII^h$ 20^h (Ursa, Canes Venatici), whence it mounts through N. Boötes, Corona, S. Draco and N. Hercules less abruptly than in the descending portion of the curve, to an inferior maximum 20 per cent above average at XVIII^h 40^m – XXI^h 20^m (Lyra and Cygnus) suffering a slight decline again between XXI^h 20^m—XXIV^h (Cygnus, Lacerta, Andromeda).

The second type curve for 'all stars' for this zone, whilst sympathizing with that of Type I in descending evenly from a maximum of 35 per cent above average in division 0^h–II^h 40^m to coincidence with average at V^h 20^m-VIII^h, parts company with the first type curve in the last mentioned division, for whilst the latter curve steadily declines to its minimum at X^h 40^m-XIII^h 20^m the second type curve as steadily rises to a secondary maximum at VIII^h-X^h 40^m, all but equal to that at 0^h–II^h 40^m, though it afterwards decends to its minimum about 30 per cent below average at X^h 40^m-XVI^h, in fair coincidence with the first type minimum.

This independent second type maximum is due to a pronounced condensation of faint E, F and H stars on both sides of meridian IX^h in Lynx and Ursa.

After the fairly coincident minima of both curves at X^h 40^m—XVI^h, the second type curve attains still a third maximum almost equal to the former one in the division XVI^h—XVIII^h 40^m, thus anticipating the maximum in the first type curve, which only occurs at XVIII^h 50^m—XXI^h 20^m in divergence from that of the second type, which drops from its third maximum to 25 per cent below average in this division.

This third second type maximum is again the result of intense local condensation of faint E, F and H stars about meridian XVIII^h on the line of division between Lyra and Hercules.

On coming to an examination of the curves in this zone for limits of 'observed brightness' 6.25, 5.75 and 5.25, the inequalities apparent for 'all stars' vanish, and the curve for Types I and II undulate in extraordinary uniformity throughout the zone, the maxima for both curves occurring in those divisions which are traversed by the galaxy.

An unique phenomenon in this zone lies in the fact that the maxima for first type spectra brighter than 6.25 in the galactic division XVIII^h 40^m—XXI^h 20^m, exceeds by about 15 per cent that occurring in the galactic division II^h 40^m—V^h 20^m, an inversion of the rule followed in all other zones for every limit of 'observed brightness,' in virtue of which the absolute maximum of the first type curve is always located in the preceding half of the galaxy. The present exception is traceable to the rich first type region in Lyra and Cygnus.

Underlying the second type curve in this zone, the separate curves for E, F, G and H, I, K exhibit the closest alliance, both by common conformity to the first type curve, where conformity exists, and by a common deviation from it, where deviation takes place. Their averages are again practically equal.

In the north equatorial zone + 30° — 0°, divided, as stated, into twelve parts of 2^h each, the first type curve starts in 0^h — II^h (Pisces) from about 15 per cent below average, mounts sharply to the absolute maximum for the zone of more than 100 per cent above average at IV^h—VI^h (the result of the rich first type region in Taurus and Orion), and then, sustained at about 65 per cent above average between VI^h and $VIII^h$ by the first type stars of the galaxy, drops precipitately to 25 per cent below average at $VIII^h$—X^h (Cancer, E. Leo, N. Hydra), whence it continues without important break through Leo, Coma, N Virgo, to the minimum of 50 per cent below average at XIV^h — XVI^h (S. Boötes, Serpens), rising again to an inferior maximum of about 50 per cent above average in the galactic division $XVIII^h$—XX^h, (N. Aquila, Sagitta, W. Vulpes), whence it falls again to 50 per cent below average at XX^h—$XXII^h$ (Delphinus-E. Vulpes, Equus and W. Pegasus) with a slight final rise in Pegasus) $XXII^h$—$XXIV^h$.

The second type curve for 'all stars' in this zone in contradistinction to the first type curve, starts in the relatively rich second type region Pisces 0^h–II^h, about 60 per cent above average, and gradually sinking to coincidence with average at that point where the first type curve attains its greatest eminence in Taurus and Orion, afterwards rises as the former falls, until it crosses the first type curve in Cancer and the adjacent parts of Leo and Hydra, maintaining its supremacy through Leo, Virgo and Coma, when it drops in XVI^h-$XVIII^h$ to its minimum of 30 per cent below average in absolute coincidence with the first type minimum in Boötes and Serpens. Here it recrosses the first type curve, and passes up beneath it in perfect sympathy to a coincident maximum at the point of intersection of the galaxy and equator in Aquila, whence both curves descend together to coincident minima in Delphinus and Equus, and the adjacent portions of Aquila, Vulpes and Pegasus.

For the limits of brightness 6.25 and 5.75, the second type curve does nowhere gain supremacy over the first type curve, but undulates in sympathy and subordination to it throughout the zone, with one point of difference which lies in the fact that, instead of the maxima in the preceding portion of the galaxy coinciding with the first type maxima in Taurus and Orion, they do not occur until the following division covering N. Monoceros, Canis Minor and Gemini.

For the limit of brightness 5.25 the first type curve in this zone still coincides as to its general character with those for the lower limits, but the various maxima and minima are more abrupt. The second type curve for this limit of brightness, on the contrary, becomes almost featureless in its evenness.

Again the E, F, and G, and H, I, K curves manifest the most marked sympathy, and their averages are practically equal.

The last set of curves are those for the southern equatorial zone 0° to 30°, divided as in the case of the northern equatorial zone, into twelve sections of 2^h each.

In Cetus and Eridanus, relatively poor in first type stars, the curve starts at about 10 per cent below average, whilst the greater proportion of second type stars in this region places that curve at the maximum of 60 per cent above average, at this point. When, however, the first type curve ascends in Orion and Canis Major to the absolute maximum for this zone of about 140 per cent above average, the second type curve passes through this region at the level of average, but after the great dip in the first type curve from 140 per cent above, to 25 per cent below average in W. Hydra and N. Argo, the second type curve cuts through it at this point, gaining decided supremacy in the rich second type region in and around Crater, from which it gradually declines through Virgo and Libra, to contact with the first type curve in Ophiuchus; after which, in the entire absence of the usually strong inferior maximum occurring in first type curves in the galactic division $XVIII^h$-XX^h, the second type curve mounts alone to a pronounced maximum of 50 per cent above average, over-lapping the flat first type curve by almost double its own value, from which it descends even more precipitately in the bare region of Capricornus to about 70 per cent below average, rising slightly to contact with the first type curve in the better furnished district in Aquarius.

The curves for limits of brightness 6.25, 5.75 and 5.25 in this zone are sympathetic with and subordinate to the first type curve. A maximum coincident with that in the latter curve is observable in all at VI^h-$VIII^h$ (Canis and Monoceros). The independent second type maximum at $XVIII^h$-XX^h (N. Sagittarius and S. Aquila) is also present in all curves, though in that for the brightest order 5.25, the superior brightness of some twenty first type stars in Ophiuchus and Scorpio creates a maximum in the first type curve at XVI^h-$XVIII^h$, more pronounced than the second type one occurring at XVIII^h-XX^h (N. Sagittarius and S. Aquila), in which only fifteen stars coming within the limit of spectrum brightness 5.25 are involved.

The absence of the first type maximum in the galactic division XVIII^h-XX^h is evidently connected with the attenuated proportions of the galaxy in Sagittarius, which is at that point a mere isthmic strip; whilst the regularity in the recurrence of the second type maximum despite the absence of the first type one, though seeming to suggest the independence of the Sagittarius group of second type stars of that all dominant first type structure, the galaxy, really accentuates, by the fact of its occurrence just here, the intimacy of first and second type stars as to their distribution.

Despite the irregularities in this set of curves, there is unimpeachable evidence of close sympathy between the two great types, and it is most patent for the limit of spectrum brightness 6.25, where the greatest number of stars is at command with reliable spectra.

The E, F, G and H, I, K curves for this zone are like a double-stranded curve in their intimate association.

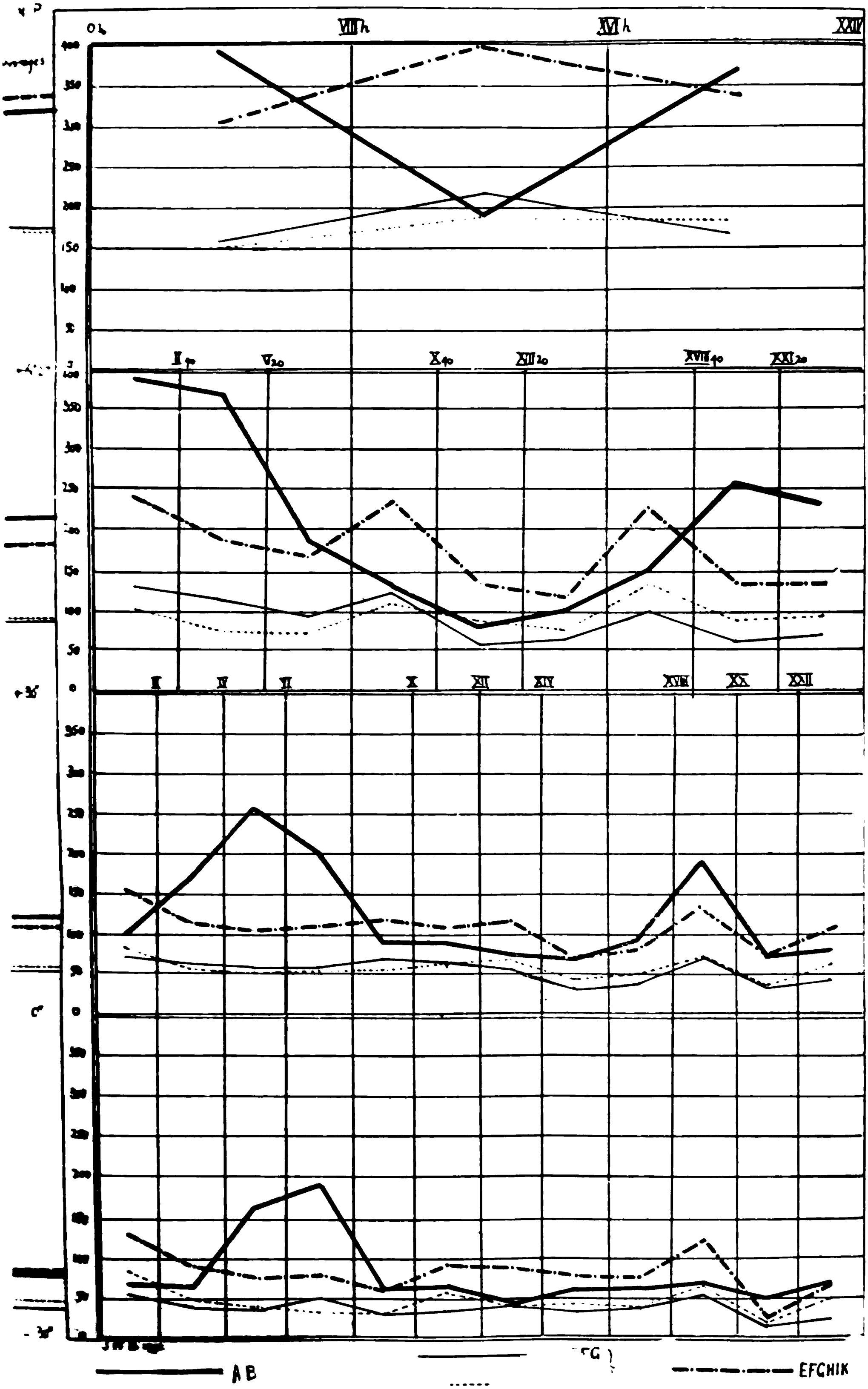
After inspection of these curves there can remain no doubt as to the solidarity of the two great types, for, whatever be the proportions of the numbers of stars entering into comparison, a manifest sympathy and parallelism of the curves representing the various groups place their common subjection to an uniform principle of distribution beyond question.

Despite the limited number of spectra of the third type in the D. C., there is an unmistakable attempt on the part of the M curve to conform to the undulations of those representing Types I and II, whilst the similar behavior of Type IV would seem to be sufficiently foreshadowed by the curve representing Chambers' catalogue of some 300 red stars. The latter type, by reason of the photographic lethargy of the light furnished by its constituents, is unrepresented in the D. C.

The unique nature of the phenomenon presented by the independent second-type maximum in the galactic region Sagittarius seemed to call for more detailed examination, and as the results are pertinent to the matter in hand they will be given here.

The following stars were identified among the brighter ones entering into the group, and their proper motions extracted from the Greenwich Catalogues. The magnitudes are photographic and from the Harvard Photometry.

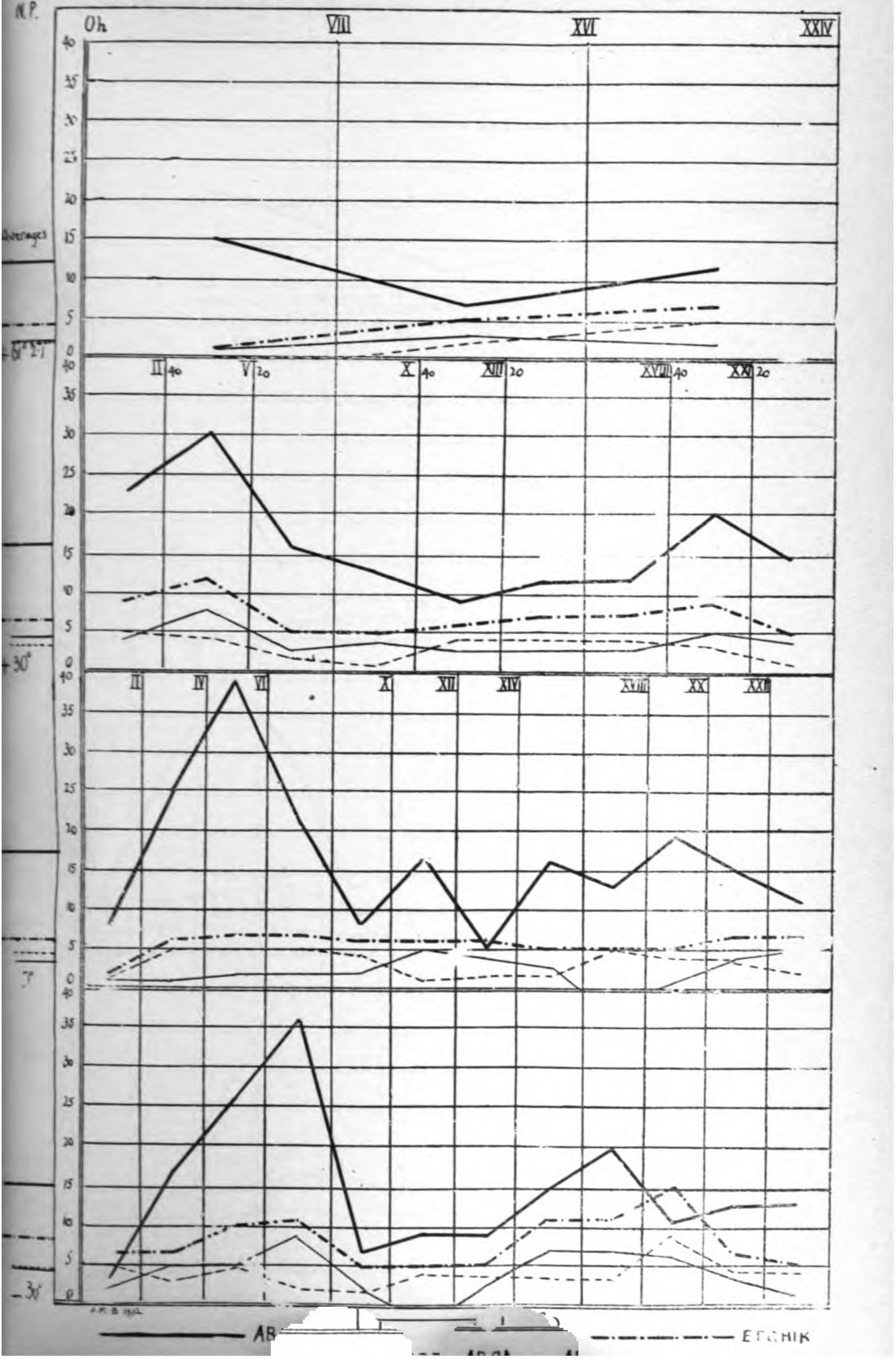
Draper Catalogue 1890 Curves of Distribution for all stars (10345) Scale = 1·00



Draper Catalogue 1890

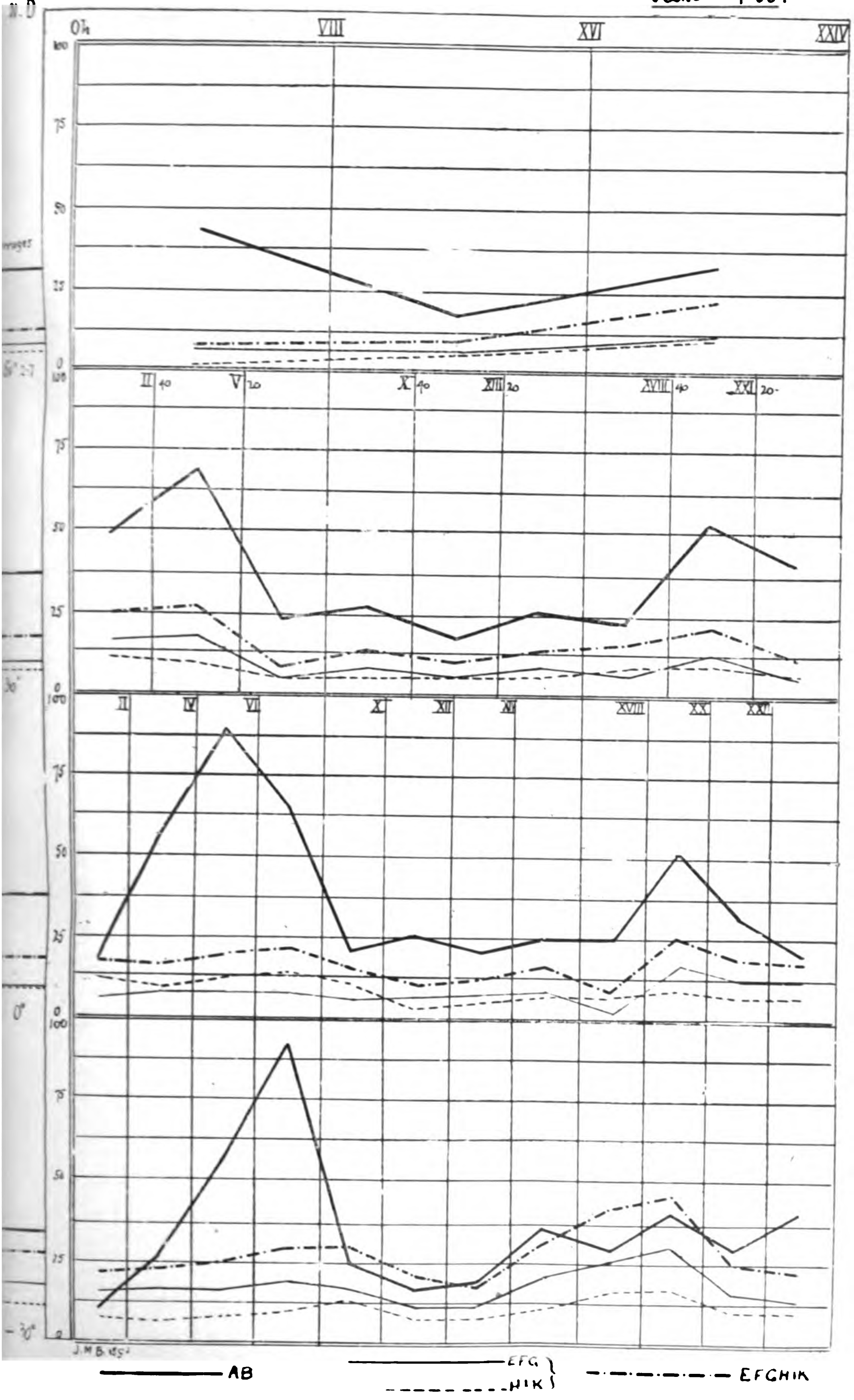
Curves of Distribution for 'Observed Brightness 5 25

Scale = 10



Draper Catalogue 1890 Curves of Distribution for Observed Brightness 5·7

Scale = 4·00.



Draper Catalogue 1890 Curves of Distribution

Chamber's Cat. Red Stars (293)

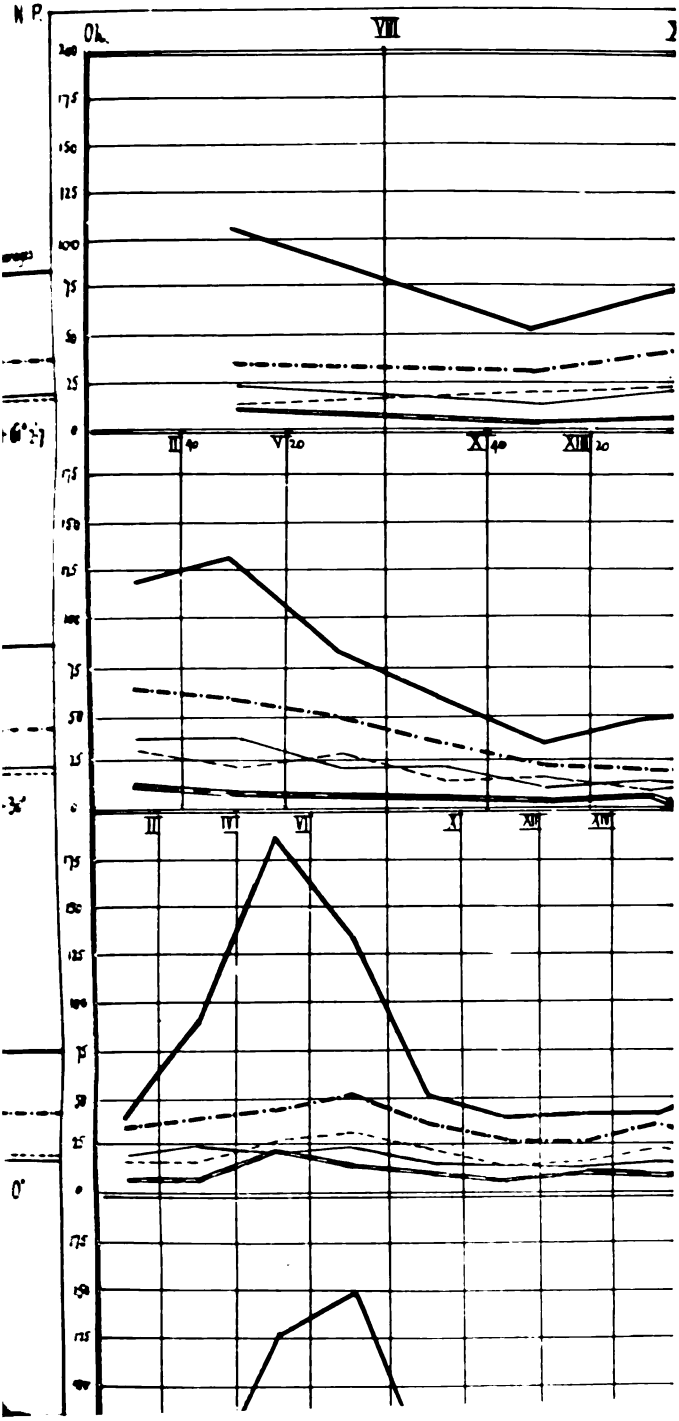
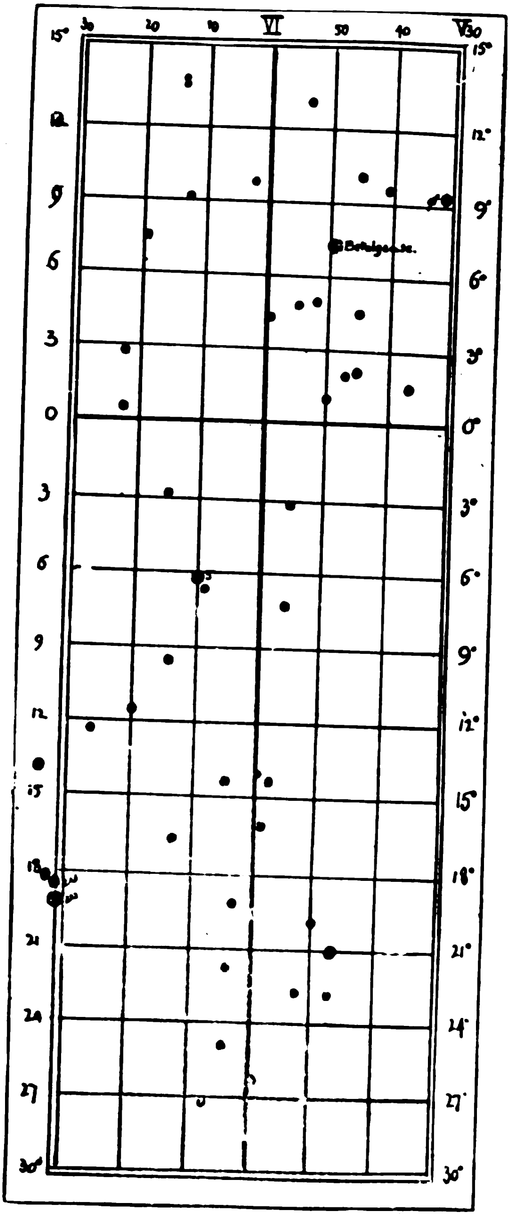


PLATE XIII.

Preceding plates numbered IX, X, XI, XII.



H I K Curves

J M B 1902

Star.	Spectrum.	Mag. H. P.	Parallel. ″	N.P.D. ″	Proper Motion. ″	Angle of Direction. °	′
4 Sagittarii..............	A	4.48	− .075	+ .04	0.085	241	56
Piazza XVII 323......	H	6.53	− .045	+ .15	0.150	196	42
7 Sagittarii	F ?	5.32	− .090	+ .03	0.095	251	34
μ^1 "	F	4.23	− 0.60	+ .01	0.061	260	32
16 "	A ?	5.89	+ .090	+ .03	0.095	108	26
Bradley 2292...........	A ?	6.55	+ .045	......	0.045	90	0
η Serpentis................	K	4.62	− .585	+ .68	0.900	220	42
21 Sagittarii............	H	5.94	− .045	+ .02	0.049	246	2
λ "	K	4.49	− .075	+ .24	0.251	181	48
Bradley 2318...........	A	4.87	......	+ .02	0.020	180	0
" 2314...........	A	6.11	......	− .04	0.040	0	0
" 2319...........	E	6.12	− .285	+ .08	0.296	254	19
24 Sagittarij	H	6.37	− .090	+ .02	0.092	257	28
1 Aquilæ......	K ?	5.04	− .060	+ .33	0.335	190	19
2 Aquilæ..................	F ?	4.92	− .015	+ .01	0.018	236	19
φ Sagittarii.............	A	3.55	+ .060	− .01	0.061	80	33
28 "	H	5.95	+ .090	− .01	0.091	83	40
5 Aquilæ......	A	5.41	+ .045	+ .05	0.067	138	0
Lalande 34875.........	K ?	5.93	......	......	......	......	......
29 Sagittarii............	H	6.09	− .030	− .03	0.042	315	0
30 "	F	5.81	+ .015	+ .03	0.033	153	27
33 "	H	6.17	+ .090	− .04	0.098	65	46
ν^1 "	H	5.65	− .060	+ .01	0.061	260	33
ν^2 "	H	5.65	+ .090	− .01	0.091	83	40
σ "	B	2.77	......	+ .08	0.080	180	0
Piazzi XVIII 225......	F	5.34	+ .105	− .03	0.109	74	4
ξ^1 Sagitarrii.............	A ?	5.26	+ .015	......	0.015	90	0
ξ^2 "	K	4.91	− .015	+ .03	0.033	206	34
12 Aquilæ.................	K	5.18	+ .015	+ .04	0.043	159	26
14 "	A	5.37	+ .075	− .06	0.096	51	21
o Sagittarii..............	I	4.99	+ .015	+ .05	0.052	163	16
τ "	H	4.53	− .120	+ .26	0.310	204	43
π "	F	3.75	− .060	+ .03	0.067	243	27
ψ "	F	5.04	......	+ .01	0.010	180	0
ρ^1 "	A	4.79	− .045	− .03	0.054	303	41
υ "	F ?	5.19	− .030	+ .05	0.058	210	58
χ^1 "	A ?	5.36	− .015	+ .03	0.033	206	34
51 "	A	5.25	− .030	......	0.030	270	0
52 "	A	4.60	+ .030	− .02	0.036	56	19
χ Aquilæ..................	A ?	5.20	− .015	......	0.015	270	0
42 Aquilæ.................	F ?	5.73	+ .150	+ .09	0.175	120	58
53 Sagittarii............	A	5.43	+ .075	− .11	0.133	214	19
Bradley 2488............	H	6.03	+ .075	− .09	0.117	219	48

There are 43 stars in all, 21 of which have their angles of direction in the third quadrant. The following table analyses these 21 stars into their respective classes, and gives the mean angle of direction for each class after rejection of spectra:

Spec.	Number of Stars.		Mean Direction rejecting ?		Mean Direction for all.
A	3	2 ?	242°	04′	225° 35′
E	1		252	28	
F	3	2 ?			
H	5	1 ?	237	43	
K	3	1 ?	203	01	

The direction of Class K is most nearly parallel to the commonly accepted direction of the Sun's way (here = 180° about), though still manifesting considerable S. W. bias, a bias rendered most evident by Class F.

In short, there exists in this region, already interesting from the large preponderance of second-type stars congregated here, a distinct drift in a direction between 203° and 252°, and, moreover, one which may be called a drift against the stream; for if the Sun's goal be located at XVII^h ±, these stars, if fixed, should obtain parallactic motions in increasing R. A. and N. P. D., placing their angles of direction in the second quadrant, a very little removed from 180°. The distribution of the angles of direction in the four quadrants, however, is shown in the following table:

Spec.	0° — 90°		90° — 180°		180° — 270°		270° — 360°
A	4	2?	1	1?	4	2?	1
B	1						
EF	1			2?	6	1?	
H	3				5	1?	1
I			1				
K			1		3	1	
	9	2?	3	3?	18	5?	2

From this it appears that the general drift is in the third quadrant, counter to the parallactic motion in right ascension, though conforming to it in N. P. D. The first quadrant shows the greatest number of apparent exceptions, but when the angles of direction in this quadrant are compared with those in the third quadrant, some suggestive results are obtained.

Thus the angle of direction of the F star Piazzi XVIII 225 is 74° ±. Now the angle for Bradley 2319, an E star a few degrees removed, is 254° ±. Consequently there exists a difference of exactly 180° between the angles of direction of proper motion in these two stars. Whilst the other members of Classes E, F have with one other exception in R. A. motions in diminishing R. A. and increasing N.P.D., Piazzi XVIII 225 has opposite signs in both ocordinates. There would appear to be small doubt that it is in reality travelling in the same absolute direction as its compeers, but owing to its smaller westerly motion, the latter is reversed and rendered easterly by the parallactic motion imposed upon it by the solar advance, whilst possessing a relatively larger northerly motion, it still retains a residue of its real motion in that direction even after having been discounted by parallactic motion.

Other instances in the same order of ideas are furnished by μ^1 Sagittarii (F) and ν^1 Sagittarii (H), which have a common proper motion of 0″.61 per an. in direction 260° 33′, whilst φ

Sagittarii (A) with reversed signs travels at an angle of 80° 33′ (260° 33′ — 180°). 2 Aquilæ (F) moves in the direction 236° 19′, 52 Sagittarii (A) towards 56° 19′ (236° 19′ — 180°); Bradley 2313 (A), 180°; Bradley 2314 (A), 0°. ξ^1 Sagittarii (A) 90°, 51 Sagittarii (A) and κ Aquilæ (A?), 270°; and so on.

Further it will be seen that angles of direction in the first and third, and second and fourth quadrants respectively, may be paired within a few degrees by the method + or — 180°, and as a result, the apparent motions in opposite quadrants are reduced to a fundamental line of motion underlying them, the task remaining to determine in which direction on this line the real motion takes place.

In the present instance we have (see table) a preponderance of outstanding motions in diminishing R. A., despite the fact that motion in such a direction must have been already curtailed by the parallactic motion resulting from the solar advance towards XVII^h ±.

Spectrum.	Diminishing R. A.	Average.	Increasing R. A.	Average.
A	5	0″.036	8	0″.054
EF	5	0 .102	3	0 .045
H	7	0 .060	4	0 .086
IK	4	0 .184	2	0 .015

Average for all = — 0 .088 .... + 0 .056

The angles of direction of the stars with diminishing R. A. must therefore be nearer approximations to the absolute direction than those of the stars whose motions are exceeded, and consequently reversed and disguised by parallactic motion.

When we examine the motions in N.P.D., parallactic motion is in the ascendant, 26 stars having increasing, and 12 only diminishing N.P.D., 5 being neutral. The two sets are made up as shown in the following table:

Spectrum.	Increasing N.P.D.	Average.	Diminishing N.P.D.	Average.
A	5	0″.034	6	0″.045
B	1	0 .080	0	......
EF	9	0 .038	1	0 .030
H	5	0 .092	5	0 .036
IK	6	0 .228	0	......

Average for all = + 0 .093................................ —0 .040

Despite the extent to which parallactic motion here tells in increasing N.P.D., there remain 12 stars which are able to pay the toll exacted by it, and still pursue, though warped to some degree, the direction of their original motions. Nevertheless, they do not suffer absolute parallactic reversal as would appear to be the case with the 18 stars with increasing N.P.D.

Now remembering that counter to the direction of parallactic motion, 21 stars move in diminishing R. A. against 17 in increasing R. A.; and noting here that 12 stars emerge from the influence of the same cause with unreversed motions in diminishing N.P.D. and further, calling to mind the cases of motion executed on the same line in opposite quadrants and at identically opposite angles; it would appear that this remarkable congeries of stars has a true drift in the direction of diminishing R. A. and diminishing N.P.D., consequently with its goal in that quadrant in which the solar apex is located.

It will be noticed that stars of Type I follow the fortunes of the group without parting company in any way with those of Type II, and exhibit the distinctive features of diminishing R. A. and N.P.D. with equal clearness.

Further, the charts give evidence of a general correspondence in magnitude in stars of Types I and II located in the same parts of the heavens. Thus in passing from Cassiopeia to Camelus, we pass from a region of relatively large magnitudes in both first and second type stars, to one where both types suffer a common diminution in magnitude. Another equally obvious example is furnished by an aggregation of some 150 faint stars upon the line of division between the constellations Lyra and Hercules. Here A, E, F and H stars contribute to the formation of a cluster equally distinguished from surrounding stars by the condensation and faintness of its constituents. Again, comparison of circumpolar regions with those at the equator, shows that the former contain stars about one magnitude fainter than the latter. These faint circumpolar stars are very numerous, and Types I and II are alike laid under contribution to furnish them, whilst their exclusion from the equatorial zones is equally operative for both types.

A further refinement in the same line of research is presented by the investigation of the polytypic or monotypic, multispecial or unispecial nature of star-streams. By polytypic and monotypic I would define streams composed of one or more of the great types; and by unispecial and multispecial, streams composed of one or more classes of the same type.

That star-streams exist, a short study of any stellar photograph will testify; still, the difficulties are great, and must in many cases be insuperable, in the reliable identification of the members of a star-stream at such limits of magnitude as shall leave any certainty as to the correct reading of the spectrum. Special difficulties, moreover, present themselves in deciphering composite streams, absolute isolation of the stream seeming the only sufficient guarantee of genuineness in polytypic streams, and isolation from stars of the same type a necessary criterion in the case of multispecial streams. But as streams only become apparent in the lower magnitudes, and consequently with increasing numbers, isolation is rendered well nigh impossible.

In fact the difficulties are such that the problem of the existence of polytypic and multispecial streams is reserved for discussion with the proper motions.

On the other hand, the charts afford ample evidence of the existence of unispecial streams. A notable instance, though by no means uniquely so, occurs where the equator cuts the galaxy in Monoceros. Of some 300 stars included between V^h 30^m and VI^h 30^m in R. A., and + 15° to — 30° in Decl., 45 are of classes H, I and K, though I and K are only represented by some three or four stars, generally of larger magnitude. These 45 stars have been all faithfully charted in the accompanying small map. Specially referring to the large S-shaped curve extending from + 9° to — 15°, it would seem that such a perfection in the curve could not possibly be attained by a chance distribution of its components. When it is stated, moreover, that this curve is projected upon a background of some 250 stars of other type and classes in undecipherable confusion, and that the latter, in the condensation about the track of the curve itself, are as 10 to 1, there can surely remain no doubt as to the genuineness of this, and of other curves existing under like conditions. Its isolation, whilst facilitating its recognition, likewise confirms its genuineness. How far the stream continues south can only be seen when the Arequipa results are made known.

Curves of the above description exist in all parts of the charts, and the general equality of magnitude and of the intervals separating the components, together with the regularity with which they are disposed along the curve, and the persistence with which the latter often develops through irregular groupings of stars of other types, would seem to place the existence of unispecial curves and streams beyond question.

There is an interesting feature in connection with these H curves, viz: the terminal stars are very often K stars, though an M star will likewise frequently be found in a similar position in an H curve. These peculiarities are exemplified by the curve given. Betelgeuse is an M star; 5 Monocerotis at the bend is a K, the star at VI^h 35^m R. A., — 14° 3′ is an I star.

As it is not the object of the present paper to examine into the proper motions in any other than a general manner, leaving the detailed examination of special districts for later attention, a general survey only of the relations of large proper motion existing among the various classes of spectra will be now attempted, with a view of disclosing points of sympathy and contrast which it is the present purpose to accentuate.

By collating Bossert's Catalogue of Proper Motions above 0″.50 with the D. C., upwards of a hundred stars were identified, and they are classified according to spectrum and amount of annual displacement in the following table:

Spec.	Above 5″	Above 4″	Above 3″	Above 2″	Above 1″.50	Above 1″.0	Above 0″.75	Above 0″.50	Total	Average. With ?	Average. Without ?
										″	″
A	1 ?	...	...	...	...	... 1 ?	1 2 ?	6 1 ?	7 5 ?	0.70	0.65*
E	...	...	...	...	...	3	1 2 ?	3 2 ?	7 4 ?	0.74	0.82
F	...	...	...	...	...	8	6	19 1 ?	33 1 ?	0.77	0.78
G	...	...	...	...	1 ?	...	1	2	3 1 ?	1.02	0.72
H	1	1 ?	1	2	1 ...	2 1 ?	2	13	22 2 ?	1.34	1.23
I	...	..	...	...	1 ?	1	2 1 ?	4 1 ?	7 3 ?	0.85	0.76
K	...	...	...	1	...	1	3	1 1 ?	6 1 ?	1.03	1.11†
M	...	...	...	...	...	...	...	1	1	......	.....

* Omitting 1830 Groombridge. † Without Arcturus = 0″.87.

From the above it will be seen that though class F is superior to any other as to the number of stars having proper motions above 0″.50, class H is superior to class F as possessing the largest number of stars with largest proper motion. The results are also interesting as showing that no class of any numerical importance save B is without representatives with large proper motion, the star with the largest proper motion in class B being ξ Ophiuchi with an annual displacement of 0″.32. This is very much in excess of the average proper motion of class B, which is about 0″.05.

An examination of the spectra of binary systems of assignable period appears to offer reliable data as to their distances, and consequently, distribution, for the fact that the components of a binary of moderate period are separable renders it probable that they are situated at distances less than those of stars whose slow revolution does not admit of their period being defined. If not, then the increased speed of revolution must be the result of incomparably greater masses or relatively minute distances of separation between the components. But if the former, we run into extremes; if the latter, the obvious effect of the reduction of the distance of separation between the components would be to render them inseparable in the telescope.

Of a list of 46 binaries compiled by Mr. Gore, I was able to identify those of the following table, which shows the distribution among the several classes of spectra:

Spectrum	A	B	E	F	G	H	K	M
	7	1	2	9	3	1	2	1
	1?	...	...	3?	...	2?	...	...

Here again class F is numerically superior; still class A, and even the small classes B and M, are able to furnish testimony to the solidarity of the stellar concourse, no class being so far withdrawn into space but some representative binary stamps it as a denizen of regions not incomparably remote from those occupied by its fellow binaries.

Further corroboration of the mixed state of society prevailing among the stars is derivable from the spectra of stars with observed parallax. The following table, put together from the list of parallaxes given in Miss A. M. Clerke's "System of the Stars," distributes them in their classes, and gives the average parallax per class:

Spectrum	A	E	F	H	K	M
	5	1	9	6	6	1
	6?	...	...	1?	4?	...
Average with ?	0″.172	...	...	0″.210	0″.141	...
Average without ?	0″.127	0″.054	0″.122	0″.217	0″.104	0″.027

Again there is no feature either in amount of parallax or number of stars involved differentiating one type decisively from another, though among the classes H manifests a superiority in the amount of parallactic displacement in accord with its greater proper motions.

A chart constructed to show at once the motions of approach and recession of Vogel's 51 stars, and the amount and direction of their proper motions, brought out further instances of sympathetic variation in the two great types. These stars are all of large magnitude and the list is made up as shown in the following table, which gives also the average tangential and radial motion for each class:

	A	B	F	G	K	L	M	Q
	25	2	6	1	12	1	2	2 = 51
Tang.	0″.258	0″.046	0″.304	0″.076	0″.425*	0″.153	0″.128	0″.071 per annum.
Rad.	12	3.2	9.46	10.1	11.08†	8.9	7.4	3.1 miles per second.

* Without Arcturus (2″.280) = 0″.257. † Without Aldebaran (+ 30.2) = 10.1 miles per second.

From an inspection of this chart it was evident that the 51 stars fall into natural groups, the members of which are associated by proximity on the sphere or relationship in tangential and radial motion as to direction and amount. It is seldom that three, if not four of these criteria fail to be satisfied by the members of a group. The groups themselves are made up as detailed below:

Group I.

XX^{h} — I^{h} R. A.

α Cygni	A	−5.0	−0.43	0.38
γ "	Q	−4.0		
α Pegasi	A	+0.8	+0.37	
β "	M?	+4.1		
ε "	K	+5.0		
α Androm.	A	+2.8		
β "	K	+7.0		
β Cass.	F	+3.2		

Group II.

I^{h} — IV^{h} R. A.

α Cassiopeia	K	− 9.5	− 0.86
γ "	Q	− 2.2	
α Ursæ Minoris	F	− 16.1	
γ Andromedæ	K	− 8.0	
α Arietis	K	− 9.2	
α Persei	F	− 6.4	
β "	A	− 11.0	

Group III.

IV^{h} — VI^{h} R. A.

α Tauri	K?	+ 30.2	+ 1.10
α Aurigæ	F	+ 15.2	
β Orionis	F	+ 10.2	
γ "	B	+ 5.7	
β Tauri	A	+ 5.0	
δ Orionis	B	+ 0.6	
ε "	A	+ 16.5	
ζ "	A	+ 9.3	
α "	M?	+ 10.7	

Group IV.

VI^{h} — VIII^{h} R. A.

β Aurigæ	A	− 17.5	−1.20
γ Geminorum	A	− 10.3	
α Canis Majoris	A?	− 9.8	
α Geminorum	A	− 18.4	
α Canis Minoris	F	− 5.7	

VIII^{h} — X^{h} R. A.

No Stars.

Group V.

X^{h} — XV^{h} R. A.

α Leonis	A	− 5.7	− 1.30
β "	A	− 7.6	
γ "	K	− 24.0	
δ "	A	− 8.9	
α Ursæ Majoris	K	− 7.2	
β "	A	− 18.2	
γ "	A	− 16 5	
ε "	A	− 18.8	
ζ "	A	− 19.4	
η "	A	− 16.3	
α Virginis	A	− 9.2	
α Boötis	K	− 4.8	
ε "	G?	− 10.1	
β Libræ	A	− 6.0	
β Herculis	K	− 22.0	

Group VI.

XV^{h} — XVIII^{h} R. A.

β Ursæ Minoris	L?	+ 8.9	+ 1.30
α Coronæ	A	+ 19.7	
α Serpentis	K?	+ 14.0	
α Ophiuchi	A	+ 11.9	

Group VII.

XVIII^{h} — XX^{h} R. A.

α Lyræ	A	− 9.5	− 1.56
α Aquilæ	A	− 22.9	

The averages have been obtained by dividing the average radial velocity per group by the general average radial velocity for all = 10.4 miles per second.

β Geminorum has been omitted, almost the whole of its motion being on the tangent.

It will be seen that the groups are all polytypic save Gr. VII; consequently the variation in direction and amount of radial motion from group to group affects all types included in the group.

Further remarkable features are brought to light by this chart, to which I may be permitted to advert *en passant*. Thus the district XX^{h}—IV^{h} R. A. is one of small motions, smallest between XX^{h}—XXIV^{h} 30^{m} ±, where they are mostly of approach, and somewhat larger between XXIV^{h} 30^{m}± —IV^{h} R. A., where they are almost exclusively of recession. Opposite to this region is a district of equal area, say VIII^h — XV^h ± R. A., in which uniform and large motion of recession takes place.

Separating these two great districts, of which the central meridians are roughly 0^h and XII^h R. A., are two others from IV^h—VIII^h on the one side of the hemisphere, and from XV^h—XX^h on the other. These are again divisible into two parts each. IV^h—VI^h R. A. contains the large motions of approach of Group III: opposite to this region, XV^h—XVIII^h R. A. contains the large motions of approach of Group VI. The region VI^h—VIII^h R. A. is occupied by the large motions of recession of Group IV; and the region opposite XVIII^h— XX^h R. A., by the large motions of recession of Group VII.

With the view of rendering more evident the solidarity of the universe, I have now passed in review evidence drawn from the following sources:— sympathetic variation in the curves of distribution of the great types, sympathetic variation in magnitude, community of drift, similarity in the possession of large proper motion, telescopic separability of binaries of assigned period, common subjection to parallactic displacement, concurrent variation in radial velocities both as to direction and amount. On the other hand, and under restrictions almost prohibitive, I have failed up to the present to discover polytypic and multispecial curves; unspecial curves, however, were found to be numerous.

STRETFORD, Lancs., October 27, 1892.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Ultra-red Spectra of the Alkalies.—In a recent number of Wieldemann's *Annalen* (No. 10, 1892), Mr. B. N. Snow describes some investigations concerning the ultra-red spectra of the Alkalies. The object of the work was to learn if the ultra-red "lines" belonged to continuations of the series of visible lines so carefully studied by Kayser and Runge. Mr. Snow used a prism spectroscope and a bolometer, and his observations seem to be consistent and accurate. Of course, the test of a line's belonging to a given series is a physical one, not a mathematical one, and the most obvious physical property to observe in the method used was the intensity. But of all the properties of a line, especially an invisible one, this is the most difficult to measure. Mr. Snow realized the difficulties of the problem, and overcame them as best he could. The result of his investigations is to show that, except in the case of sodium and lithium, the ultra-red "lines" do not form part of the visible series. He does not seem, though, to have studied the lines themselves independently, to see if they formed separate series. This last suggestion would appear the more plausible judging from all analogies.

Unusual Appearance in a Sun-Spot.—We have received from Miss E. Brown a sketch of the anomalous facula observed in a Sun-spot on Aug. 21, and noted in our last number. In her letter she adds, "On Nov. 10 (1892) 1.15, G. M. T, I observed a similar patch of faculous light between the umbra and penumbra of a Sun-spot in Long. 296°, Lat. 22° N. It was of very much smaller proportions and equally evanescent, having disappeared in less than three hours."

From these various appearances it is evident that the Sun should be much more constantly observed than is now the case. Amateurs with telescopes of any aperture would do well to enter this fruitful and interesting field. Even the smallest telescopes will suffice for the work, and the method of observing the Sun's image projected on a screen of white paper will be found most effective.

The Sun's Effect on Terrestrial Magnetism.—We wish to call attention to the following very important considerations presented by Lord Kelvin in his recent Presidential Address to the Royal Society, and printed in *Nature* for Dec. 1, 1892.

"Guided by Maxwell's "electro-magnetic theory of light," and the undulatory theory of propagation of magnetic force which it includes, we might hope to perfectly overcome a fifty years' outstanding difficulty in the way of believing the Sun to be the direct cause of magnetic storms in the Earth, though hitherto every effort in this direction has been disappointing. This difficulty is clearly stated by Professor W. G. Adams, in the following sentences, which I quote from his Report to the British Association of 1881 (p. 469) "On Magnetic Disturbances and Earth Currents:"—"Thus we see that the magnetic changes which take place at various points of the Earth's surface at the same instant are so large as to be quite comparable with the Earth's total magnetic force; and in order that any cause may be a true and sufficient one, it must be capable of producing these changes rapidly."

"The primary difficulty, in fact, is to imagine the Sun a variable magnet or electro-magnet, powerful enough to produce at the Earth's distance changes of magnetic force amounting, in extreme cases, to as much as one-twentieth or one-thirtieth, and frequently, in ordinary magnetic storms, to as much as one four-hundredth of the undisturbed terrestrial magnetic force.

"The Earth's distance from the Sun is 228 times the Sun's radius, and the cube of this number is about 12,000,000. Hence, if the Sun were, as Gilbert found the Earth to be, a globular magnet, and if it were of the same average intensity of magnetization as the Earth, we see, according to the known law of magnetic force at a distance, that the magnetic force due to the Sun at the Earth's distance from it, in any direction, would be only a twelve-millionth of the actual force of terrestrial magnetization at any point of the Earth's surface in a corresponding position relatively to the magnetic axis. Hence the Sun must be a magnet* of not much short of 12,000 times the average intensity of the terrestrial magnet (a not absolutely inconceivable supposition, as we shall presently see) to produce,

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* The Moon's apparent diameter being always nearly the same as the Sun's, the statements of the last four sentences are applicable to the Moon as well as to the Sun, and are important in connection with speculation as to the cause of the lunar disturbance of terrestrial magnetism, discovered nearly fifty years ago by Kreil and Sabine.

by direct action simply as a magnet, any disturbance of terrestrial magnetic force sensible to the instruments of our magnetic observatories.

"Considering probabilities and possibilities as to the history of the Earth from its beginning to the present time, I find it unimaginable but that terrestrial magnetism is due to the greatness and the rotation of the Earth. If it is true that terrestrial magnetism is a necessary consequence of the magnitude and the rotation of the Earth, other bodies comparable in these qualities with the Earth, and comparable also with the Earth in respect to material and temperature, such as Venus and Mars, must be magnets comparable in strength with the terrestrial magnet, and they must have poles similar to the Earth's north and south poles on the north and south sides of their equators, because their directions of rotation, as seen from the north side of the ecliptic, are the same as that of the earth. It seems probable, also, that the Sun, because of its great mass and its rotation in the same direction as the Earth's rotation, is a magnet with polarities on the north and south sides of its equator, similar to the terrestrial northern and southern magnetic polarities. As the Sun's equatorial surface-velocity is nearly four and a half times the Earth's, it seems probable that the average solar magnetic moment exceeds the terrestrial considerably more than according to the proportion of bulk. Absolutely ignorant as we are regarding the effect of cold solid rotating bodies such as the Earth, or Mars, or Venus, or of hot fluid rotating bodies such as the Sun, in straining the circumambient ether, we cannot say that the Sun might not be 1000, or 10,000, or 100,000 times as intense a magnet as the Earth. It is, therefore, a perfectly proper object or investigation to find whether there is, or is not, any disturbance of terrestrial magnetism, such as might be produced by a constant magnet in the Sun's place with its magnetic axis coincident with the Sun's axis of rotation. Neglecting for the present the seven degrees of obliquity of the Sun's equator, and supposing the axis to be exactly perpendicular to the ecliptic, we have an exceedingly simple case of magnetic action to be considered: a magnetic force perpendicular to the ecliptic at every part of the Earth's orbit and varying inversely as the cube of the Earth's distance from the Sun. The components of this force parallel and perpendicular to the Earth's axis are, respectively, 0.92 and 0.4 of the whole; of which the former could only be perceived in virtue of the varying distance of the Earth from the Sun in the course of a year; while the latter would give rise to a daily variation, the same as would be observed if the red ends of terrestrial magnetic needles were attracted towards an ideal star of declination 0° and right ascension 270°. Hence, to discover the disturbances of terrestrial magnetism, if any there are, which are due to direct action of the Sun as a magnet, the photographic curves of the three magnetic elements given by each observatory should be analysed for the simple harmonic constituent of annual period and the simple harmonic constituent of period equal to the sidereal day. We thus have two very simple problems, each of which may be treated with great ease separately by a much simplified application of the principles on which Schuster has treated his much more complex subject, according to Gauss' theory as to the external or internal origin of the disturbance, and Professor Horace Lamb's investigation of electric currents induced in the interior of a globe by a varying external magnet. The sidereal diurnal constituent which forms the subject of the second of these simplified problems is smaller, but not much smaller, than the solar diurnal term which, with the solar semi-diurnal, the solar ter-diurnal, the solar quarter-diurnal constituents form the subjects of Schuster's paper. The conclusion at which he has arrived, that the source of the disturbance is external, is surely an ample reward for the great labor he has bestowed on the investigation hitherto; and I hope he may be induced to undertake the comparatively slight extension of his work which will be required for the separate treatment of the two problems of the sidereal diurnal and the solar annual constituents, and to answer for each the question:—Is the source external or internal?

"But even though external be the answer found in each case, we must not from this alone assume that the cause is direct action of the Sun as a magnet. The largeness of the solar semi-diurnal, ter-diurnal, and quarter-diurnal constituents found by the harmonic analysis, none of which could be explained by the direct action of the Sun as a magnet, demonstrate relatively large action of some other external influence, possibly the electric currents in our atmosphere, which Schuster suggested as a probable cause. The cause, whatever it may be, for the semi-diurnal and higher constituents would also probably have a variation in the solar diurnal period on account of the difference of temperature of night and day, and a sidereal and annual period on account of the difference of temperature between winter and summer.

Even if, what does not seem very probable, we are to be led by the analysis to believe that magnetic force of the Sun is directly perceptible here on the Earth, we are quite certain that this steady force is vastly less in amount than the abruptly varying force which, from the time of my ancestor in the Presidential Chair, Sir Edward Sabine's discovery,* forty years ago, of an apparent connection between Sunspots and terrestrial magnetic storms, we have been almost compelled to attribute to disturbing action of some kind at the Sun's surface.

"As one of the first evidences of this belief, I may quote the following remarkable sentences from Lord Armstrong's Presidential Address to the British Association at Newcastle, in 1863:—

'"The sympathy also which appears to exist between forces operating in the Sun and magnetic forces belonging to the Earth merits a continuance of that close attention which it has already received from the British Association, and of labors such as General Sabine has, with so much ability and effect, devoted to the elucidation of the subject. I may here notice that most remarkable phenomenon which was seen by independent observers at two different places, on September 1, 1859. A sudden outburst of light, far exceeding the brightness of the Sun's surface, was seen to take place, and sweep like a drifting cloud over a portion of the solar face. This was attended with magnetic disturbances of unusual intensity, and with exhibitions of aurora of extraordinary brilliancy. The identical instant at which the effusion of light was observed was recorded by an abrupt and strongly-marked deflection in the self-registering instrument at Kew. The phenomenon as seen was probably only part of what actually took place, for the magnetic storm in the midst of which it occurred commenced before, and continued after the event. If conjecture be allowable in such a case, we may suppose that this remarkable event had some connection with the means by which the Sun's heat is renovated. It is a resonable supposition that the Sun was at that time in the act of receiving a more than usual accession of new energy; and the theory which assigns the maintenance of its power to cosmical matter, plunging into it with that prodigious velocity which gravitation would impress upon it as it approached to actual contact with the solar orb, would afford an explanation of this sudden exhibition of intensified light, in harmony with the knowledge we have now attained, that arrested motion is represented by equivalent heat."

"It has certainly been a very tempting hypothesis, that quantities of meteoric

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* Communication to the Royal Society, March 18, 1852 (*Phil. Trans.*, vol. clxii, p. 143.)

matter suddenly falling into the Sun is the cause, or one of the causes, of those disturbances to which magnetic storms on the Earth are due. We may, indeed, knowing that meteorites do fall into the Earth, assume without doubt that much more of them fall, in the same time, into the Sun. Astronomical reasons, however, led me long ago to conclude that their quantity annually, or per century, or per thousand years, is much too small to supply the energy given out by the Sun in heat and light radiated through space, and led me to adopt unqualifiedly Helmholtz's theory, that work done by gravitation on the shrinking mass is the true source of the Sun's heat, as given out at present, and has been so for several hundred thousand years, or several million years. It is just possible, however, that the outburst of brightness described by Lord Armstrong may have been due to an extraordinarily great and sudden falling in of meteoric matter, whether direct from extra-planetary space, or from orbital circulation round the Sun. But it seems to me much more probable that it was due to a refreshed brightness produced over a larger area of the surface than usual by brilliantly incandescent fluid rushing up from below, to take the place of matter falling down from the surface, in consequence of being cooled in the regular *regime* of solar radiation. It seems, indeed, very improbable that meteors fall in at any time to the Sun in sufficient quantity to produce dynamical disturbances at his surface at all comparable with the gigantic storms actually produced by hot fluid rushing up from below, and spreading out over the Sun's surface.

"But now let us consider for a moment the work which must be done at the Sun to produce a terrestrial magnetic storm. Take, for example, the magnetic storm of June 25, 1885, of which Adams gives particulars in his paper of June, 1891 (*Phil. Trans.* p. 139, and Pl. 9). We find at eleven places, St. Petersburg, Stonyhurst, Wilhelmshaven, Utrecht, Kew, Vienna, Lisbon, San Fernando, Colaba, Batavia and Melbourne, the horizontal force increased largely from 2 to 2:10 P. M., and fell at all the places from 2:10 to 3 P. M., with some rough ups and downs in the interval. The storm lasted altogether from about noon to 8 P. M. At St. Petersburg, Stonyhurst and Wilhelmshaven, the horizontal force was above bar py 0.00075, 0.00088, and 0.00090 (C.G.S. in each case) at 2:10 P. M.; and below par by 0.0007, 0.00066, 0.00075 at 3 o'clock. The mean value for all the eleven places was nearly 0.0005 above par at 2^h 10^m, and 0.0005 below par at 3^h. The photographic curves show changes of somewhat similar amounts following one another very irregularly, but with perfectly simultaneous correspondence at the eleven different stations, through the whole eight hours of the storm. To produce such changes as these by any possible dynamical action within the Sun, or in his atmosphere, the agent must have worked at something like 160 million million million million horse-power[*] (12×10^{35} ergs per sec.), which is about 364 times the total horse power (3.3×10^{33} ergs per sec.) of the solar radiation. Thus, in this eight hours of a not very severe magnetic storm, as much work must have been done by the Sun in sending magnetic waves out in all directions through space as he actually does in four months of his regular heat and light. This result, it seems to me, is absolutely conclusive against the supposition that terrestrial magnetic storms are due to magnetic action of the Sun; or to any kind of dynamical action taking place within the Sun, or in connection with hurricanes in his atmosphere, or anywhere near the Sun outside.

"It seems as if we may also be forced to conclude that the supposed connection between magnetic storms and Sunspots is unreal, and that the seeming agreement between the periods has been a mere coincidence.

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[*] 1 horse-power = 7.46×10^9 ergs per sec.

"We are certainly far from having any reasonable explanation of any of the magnetic phenomena of the earth; whether the fact that the Earth is a magnet; that its magnetism changes vastly, as it does from century to century; that it has somewhat regular and periodic annual, solar diurnal, lunar diurnal, and sidereal diurnal variations; and (as marvelous as the secular variation) that it is subject to magnetic storms. The more marvellous, and, for the present inexplicable, all these subjects are, the more exciting becomes the pursuit of investigations which must, sooner or later, reward those who persevere in the work. We have at present two good and sure connections between magnetic storms and other phenomena: the aurora above, and the earth currents below, are certainly in full working sympathy with magnetic storms. In this respect the latter part of Mr. Ellis's paper is of special interest, and it is to be hoped that the Greenwich observations of Earth currents will be brought thoroughly into relation with the theory of Schuster and Lamb, extended, as indeed Professor Schuster promised to extend it, to include not merely the periodic diurnal variations, but the irregular sudden changes of magnetic force taking place within any short time of a magnetic storm."

The Astronomical Congress at Chicago in 1893.—Preparations for an International Congress embracing Mathematics, Astronomy and Astro-Physics, to be held in connection with the Columbian Exposition, are going rapidly forward, and the invitations will soon be sent out. The general Congress will convene on August 21, 1893, and afterwards separate into three sections. The local committee is constituted as follows:

GENERAL COMMITTEE.
Professor George W. Hough, Chairman.
Mr. S. W Burnham, Vice-Chairman.

SECTIONAL COMMITTEES.

Mathematics: Professor E. W. Moore, Chairman; Professor E. S. White, Professor Oskar Bolza, Professor Heinrich Maschke.

Astronomy: Professor G. W. Hough, Chairman: Mr. S. W. Burnham, Professor Malcolm McNeill, Professor G. C. Comstock, Professor W. W. Payne, Mr. G. A. Douglass, Mr. R. W. Pike.

Astro-Physics: Professor G. E. Hale, Chairman; Professor Henry Crew, Professor C. B. Thwing.

Errata.—In Professor Campbell's article in ASTRONOMY AND ASTRO-PHYSICS, November, 1892, pp. 807, 808, columns 3 and 6, the *periods* followed by two decimals should be *hyphens* followed by the third and fourth places of tenth-metres. Thus 5456.47 really means the group of lines 5456, 5447, and for brevity it was intended to be written 5456-47. In plate XL accompanying the same article, the letter C over the spectrum has been transformed by the reproducer into an O.

On the History of the Bolometer.—At a time when so many men are at work in each department of experimental science an undisputed discovery appears to be the exception rather than the rule. This is notably true of useful electrical devices. Claims of priority are so often well-based, and again so often ill-founded, that one finds it difficult to decide upon them according to any general rule.

On the one hand, the crop of astronomers (?) that have seen the Fifth Satellite of Jupiter before Barnard is easily disposed of; while, on the other hand, one is confronted with such genuine double discoveries as those of Lockyer and Janssen, Gray and Bell, Leverrier and Adams.

But between these two extremes, one meets many cases in which it is not easy to say whose is the priority, or even then, whose the honor.

A case of this kind was presented, by Mr. Kurlbaum, to the Physical Society of Berlin at its session of Jan. 8th, 1892.

It was here set forth that the bolometer was devised by Soanberg in 1851, some thirty years before Langley's work with it.

We have taken occasion to read Soanberg's* description of his Differential Thermometer, and it leaves no doubt whatever that he employed a Wheatstone's Bridge in essentially the same manner, and for essentially the same purpose as Langley.

For instance, Soanberg used an astatic galvanometer which would indicate differences of temperature amounting to no more than 1/650° C. He also used lamp black on that arm of the bridge whose variation in resistance was to indicate variation of temperature. In short the priority is Soanberg's.

But, as everybody knows, Prof. Langley is the man who has given the bolometer "a local habitation and a name."

He it was who recognized the adaptability of the instrument, and the tremendous importance of the work it was capable of doing, and who did the work, spending presumably more than nine tenths of his time in avoiding a thousand and one difficulties of which the uninitiated know nothing.

This remark is not intended as any eulogy on Prof. Langley, or as any detraction from the work of Soanberg, but merely as an expression of opinion that, in all such cases, original sources should be consulted, the facts ascertained as exactly as possible, and then care be used to see that *mere* antecedence does not come into the balance against development of a new method and results obtained.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR FEBRUARY.

Mercury will be at superior conjunction Feb. 16, and will therefore not be visible during this month.

Venus rises only an hour earlier than the Sun during February, and is therefore not in good position for observation.

Mars will be visible during the early part of the evening, but his distance will be so great as to make observations of the surface markings unsatisfactory. Mars will be in conjunction with the Moon Feb. 21 at 8^h A. M. central time. There will be an occultation of the planet as seen from the equatorial regions of the other side of the Earth.

Jupiter will also be visible in the early morning during February, the two planets, Jupiter and Mars, being in the same region of the sky towards the southwest. There will be an occultation of Jupiter by the Moon Feb. 20 at about 9 A. M. central time. It will be visible in Asia.

From *The Observatory* for December, 1892, we have the following ephemeris of the fifth satellite of Jupiter by Mr. A. Marth:

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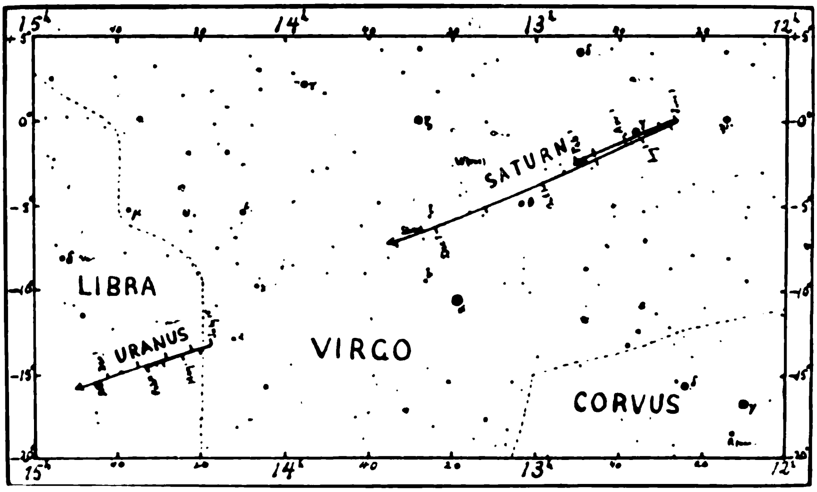
[*] *Soanberg (A. F.)*: Ueber Messung des Leitungs-wiederstands für Electrische Ströme und über ein galvanisches Differential-thermometer. Pogg. Ann. Bd. 84, pp. 411–418.

	Central Time of Greatest Elongation. East. h m	Distance from Planet's Center. West. h m	"
1893 Jan. 10	4 00 P. M.	9 58 P. M.	51
20	3 00 "	9 09 "	49
30	2 22 "	8 20 "	48

Saturn rises at about 10 P. M. on Feb. 1, and will be in good position for observation after midnight. The accompanying chart will indicate where to look for the planet. The constellation Virgo at midnight Feb. 1 will be a little south of east and about half way from the horizon to the zenith. The planet is now moving very slowly eastward in the center of the constellation but will soon turn westward, making the loop indicated on the chart, until June 9, when it will again take up its journey to the east. The plane of the rings now makes an angle of about 9° with the line of sight, so that the rings may be distinctly seen. Saturn will be in conjunction with the Moon, 1° 02′ north, Feb. 5 at 11^h 16^m A. M. central time.



Uranus is a little farther to the east than Saturn. His path for this year is shown on the accompanying chart with that of Saturn. It will be noticed that the planet is almost on a direct line between the stars α Libræ and λ Virginis. Uranus will be stationary Feb. 13, and after that move westward until July 14, when he will turn on his course and continue direct motion toward the east for the remainder of the year. There will be a conjunction of Uranus with the moon Feb. 9 at 7^h 29^m P. M., the former being 1° 22′ north of the latter.

Neptune will be stationary in Taurus Feb. 17 at 5^h 16^m A. M., and will after that move slowly eastward. For chart of his path see Dec., 1892, number of this journal, p. 937.

MERCURY.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Feb. 5......	20 48.3	– 19 55	7 03 A. M.	11 43.7 A. M.	4 24 P. M.
15......	21 57.7	– 14 35	7 09 "	12 13.7 P. M.	5 18 "
25......	23 07.3	– 6 55	7 08 "	12 43.8 "	6 20 "

Date. 1892.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			VENUS.		
Feb. 5	19 51.3	− 21 17	6 13 A. M.	10 47.2 A. M.	3 21 P. M.
15	20 43.5	− 18 53	6 14 "	10 59.8 "	3 45 "
25	21 33.9	− 15 34	6 11 "	11 10.8 "	4 11 "
			MARS.		
Feb. 5	1 37.3	+ 10 39	9 46 A. M.	4 32.2 P. M.	11 18 P. M.
15	2 02.4	+ 13 06	9 22 "	4 17.9 "	11 14 "
25	2 28.1	+ 15 24	8 57 "	4 04.2 "	11 12 "
			JUPITER.		
Feb. 5	1 16.8	+ 6 53	9 41 A. M.	4 11.7 P. M.	10 42 P. M.
15	1 23.3	+ 7 35	9 05 "	3 38.9 "	10 12 "
25	1 30.5	+ 8 20	8 29 "	3 06.7 "	9 44 "
			SATURN.		
Feb. 5	12 50.3	− 2 36	9 50 P. M.	3 43.2 A. M.	9 36 A. M.
15	12 49.0	− 2 26	9 09 "	3 02.6 "	8 56 "
25	12 47.2	− 2 12	8 27 "	2 21.5 "	8 16 "
			URANUS.		
Feb. 5	14 33.7	− 14 37	12 26 A. M.	5 30 3 A. M.	10 35 A. M.
15	14 33.8	− 14 37	11 43 P. M.	4 47.1 "	9 51 "
25	14 33.5	− 14 35	11 03 "	4 07.5 "	9 12 "
			NEPTUNE.		
Feb. 5	4 28.2	+ 20 12	11 54 A. M.	7 22.5 P. M.	2 51 A. M.
15	4 28.1	+ 20 12	11 15 "	6 43.1 "	2 12 "
25	4 28.2	+ 20 13	10 35 "	6 03.8 "	1 32 "
			THE SUN.		
Feb. 5	21 18.7	− 15 41	7 14 A. M.	12 14.3 P. M.	5 15 P. M.
15	21 58.2	− 12 24	7 00 "	12 14.3 "	5 29 "
25	22 36.5	− 8 48	6 44 "	12 13.1 "	5 42 "

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
Feb. 2	B.A.C. 3837	6.3	18 56	118	19 55	305	0 59
7	B.A.C. 4896	6.6	13 31	81	13 21	343	0 50
18	4 Ceti	6.0	6 12	125	6 36	170	0 24
18	5 Ceti	6.0	6 26	115	6 58	181	0 32
18	B.A.C 5	5.7	6 40	81	7 34	217	0 54
20	54 Ceti	5.5	6 57	53	8 06	250	1 09
21	π Arietis	5.7	9 32	34	10 20	290	0 48
22	B. A.C 1189	6.0	10 54	85	11 51	255	0 57
24	136 Tauri	5.3	11 02	44	11 45	325	0 45
26	ω^1 Cancri	6.0	11 54	97	13 01	308	1 07
26	ω^2 Cancri	6.3	12 36	145	13 32	258	0 56

Configuration of Jupiter's Satellites at 8h p. m. Central Time.

Feb.		Feb.		Feb.	
1	3 2 1 ○ 4	11	1 4 ○ 2 3	21	4 ○ 3 1 2
2	♃ 3 2 ○ 4	12	2 ○ 1 4 3	22	4 3 1 2 ○
3	4 3 ○ 1 2	13	1 ○ 3 4 ●	23	4 3 2 ○ 1
4	4 1 ○ 2 3	14	3 ○ 1 2 4	24	4 3 1 ○ 2
5	4 2 ○ 1 3	15	3 1 2 ○ 4	25	♃ 4 ○ 3 2
6	4 1 ○ 2 3	16	3 2 ○ 1 4	26	4 2 ○ 1 3
7	4 3 ○ 1 2	17	3 ○ 2 4 ●	27	4 1 2 ○ 3
8	4 3 2 1 ○	18	1 ○ 2 3 4	28	○ 3 1 2●
9	4 3 2 ○ 1	19	2 ○ 1 4 3		
10	4 3 ○ 1 2	20	1 4 2 ○ 3		

Phenomena of Jupiter's Satellites.

1893.	h	m					h	m			
Feb. 1	8	12	P. M.	I	Oc. Dis.	Feb. 14	8	34	P. M.	III	Sh. In.
2	5	20	"	I	Tr. In.	15	6	17	"	II	Sh. Eg.
	6	35	"	I	Sh. In.	17	6	41	"	I	Oc. Dis.
	7	35	"	I	Tr. Eg.	18	4	55	"	I	Sh. In.
	8	48	"	I	Sh. Eg.		6	05	"	I	Tr. Eg.
3	6	06	"	I	Ec. Re.		7	08	"	I	Sh. Eg.
7	6	30	"	III	Sh. Eg.	21	8	12	"	III	Tr. In.
9	7	20	"	I	Tr. In.	22	6	28	"	II	Sh. In.
	8	30	"	I	Sh. In.		6	55	"	II	Tr. Eg.
10	4	41	"	I	Oc. Dis.	25	5	51	"	I	Tr. In.
	8	01	"	I	Ec. Re.		6	51	"	I	Sh. In.
11	5	12	"	I	Sh. Eg.		8	05	"	I	Tr. Eg.
13	6	21	"	II	Oc. Dis.	26	6	21	"	I	Ec. Re.
14	6	17	"	III	Tr. Eg.						

Minima of Variable Stars of the Algol Type.

U CEPHEI.

R. A. .... $0^h\ 52^m\ 32^s$
Decl .... $+81^\circ\ 17'$
Period .... $2d\,11^h\,50^m$
1893.

Feb. 4	11 P. M.
9	11 "
14	11 "
19	10 "
24	10 "

ALGOL.

R. A. .... $3^h\ 01^m\ 01^s$
Decl .... $+40^\circ\ 32'$
Period .... $2d\,20^h\,49^m$

Feb. 14	11 P. M.
17	8 "

R. CANIS MAJORIS.

R. A. .... $7^h\ 14^m\ 30^s$
Decl .... $-16^\circ\ 11'$
Period .... $1d\ 03^h\,16^m$

Feb. 1	9 P. M.
8	5 "
9	8 "
10	11 "
17	7 "
18	10 "
25	6 "
26	9 "
28	12 "

S CANCRI.

R. A. .... $8^h\ 37^m\ 39^s$
Decl .... $+19^\circ\ 26'$
Period .... $9d\,11^h\,38^m$

Feb. 10	5 P. M.
20	4 A. M.

S ANTLIÆ.

R. A. .... $9^h\ 27^m\ 30^s$
Decl .... $-28^\circ\ 09'$
Period .... $7^h\ 47^m$

Feb. 1	9 P. M.
2	5 A. M.
2	8 P. M.
3	3 A. M.
4	2 "
5	2 "
6	1 "
7	12 "
7	12 P. M.
8	11 "
9	10 "
10	10 "
11	9 "
12	5 A. M.
12	9 P. M.
13	4 A. M.
14	4 "
14	7 P. M.
15	4 A. M.
16	2 "
17	2 "
18	1 "
19	12 "
19	12 P. M.
20	11 "
21	10 "
22	10 "
23	9 "
24	5 A. M.
24	8 P. M.
25	4 A. M.
25	8 P. M.
26	3 A. M.

S ANTLIÆ CONT.

Feb. 26	7 P. M.
27	3 A. M.
28	2 "

δ LIBRÆ.

R. A. .... $14^h\ 55^m\ 06^s$
Decl .... $-\ 8^\circ\ 05'$
Period ....$2d\ 7^h\ 51^m$

Feb. 3	6 A. M.
10	5 "
17	5 "
24	4 "

U CORONÆ.

R. A. .... $15^h\ 13^m\ 43^s$
Decl .... $+32^\circ\ 03'$
Period .... $3d\ 10^h\ 51^m$

Feb. 3	12 A. M.
20	7 "
27	4 "

U OPHIUCHI.

R. A.. .... $17^h\ 10^m\ 56^s$
Decl .... $+\ 1^\circ\ 20'$
Period .... $0d\ 20^h\ 8^m$

Feb. 4	5 A. M.
5	2 "
9	6 "
10	2 "
14	7 "
15	3 "
20	4 "
20	12 P. M.
25	5 A. M.
26	1 "

Phases and Aspects of the Moon.

		d	h m	
Last Quarter	Feb.	8	2 12	P. M.
Apogee	"	8	9 48	"
New Moon	"	16	10 17	A. M.
Perigee	"	21	2 42	P. M.
First Quarter	"	23	8 14	A. M.

COMET NOTES.

The comet announced by Freeman Nov. 24, appears to have been a nebula.

Holmes' comet is growing rapidly fainter but has expanded and become very diffuse. There is a slight condensation about the nucleus, 1′ or more in diamete., which is about all that can be distinguished with a large telescope. With a four or five-inch telescope and very low power the nebulosity is seen to extend over a width of from 15′ to 20′ and a length of nearly 2°. If the comet keeps on diminishing in brightness it will soon be beyond the possibility of accurate measurement. Our last observation was on the night of Dec. 23.

Brooks' comet *d* 1892, is quite bright, but is now too far south for observation in this latitude.

Brooks' last comet *g* 1892 should be growing brighter according to an ephemeris which we have extending to Dec. 31. It is now visible in the morning, but in January will be continually above the horizon. Jan. 1 it will be in the constellation of Draco just south of the Little Bear.

Course of Holmes' Comet during the Summer of 1892.—In *Astr. Nach.*, No. 3133, Mr. Berberich gives the following ephemeris of the path of Comet Holmes during the past summer, with the hope of finding its impression upon some of the photographs which may have been taken. It is reported that several amateurs saw the comet prior to Nov. 6, but supposed it to be a known nebula. We learn from *The Observatory*, December, 1892, that Mr. Schooling has found a trace of the comet on one of his photographs taken at Hammersmith, Eng., Oct. 18.

Berlin Midnight.	R. A.		Decl.		log *r*	log. Δ	Br.
1892.	h	m	°	′			
May 30	0	15.8	+ 5	20	0.3383	0.3837	0.47
June 19	0	44.5	11	23	0.3372	0.3451	0.56
July 9	1	09.6	17	28	0.3381	0.3029	0.68
29	1	28.7	23	32	0.3409	0.2582	0.83
Aug. 18	1	40.9	29	20	0.3455	0.2149	0.99
Sept. 7	1	40.7	34	32	0.3518	0.1770	1.14
27	1	27.3	38	15	0.3595	0.1535	1.23
Oct. 17	1	05.6	+39	35	0.3685	0.1531	1.18

It will be seen that the theoretical brightness of the comet was not much greater at the maximum in September than it was at the time of discovery, so that it is not so wonderful after all that the comet was not seen earlier.

Elements of Comet *f* 1892 (Holmes).—Numerous computers have been at work on this comet. The best elements which we have at hand are the following:

Computer.	Kreutz.	Berberich.	Schulhof.
	Berlin M. T.	Berlin M. T.	Paris M. T.
T	1892 June 9.9978	June 20.7357	July 15.6550
ω	13° 37′ 49″.0	18° 12′ 14″.8	31° 27′ 58″.4
☊	331 31 03 .7	331 04 23 .2	328 32 40 .7
i	20 54 08 .1	20 39 38 .8	20 26 46 .8
e	0.417209	0.393144	0.355386
μ	500″.407	523″.335	......
log *a*	0.567123	0.554151	......
Period	7.09 years	6.78 years	6.72

The first set of these elements represents the observations quite closely up to Dec. 23, the corrections to the ephemeris on that date being $+ 13^s$ in R. A. and

+ 0′.4 in Decl. We give below an ephemeris for January based upon these elements. Mr. Berberich's elements represent the observations better in R. A. but not quite so well in Decl. Mr. Berberich points out the fact that according to his elements, the eccentricity of this orbit is smaller than that of any other known comet. Its aphelion distance 5.0 is less than the distance of Jupiter from the Sun and its perihelion distance greater than that of Mars. Its path is almost wholly within the Asteroid zone. This suggests the query, which has frequently occurred to us when considering the unusual behavior of this comet, whether it may be the result of a collision between two asteroids. Mr. Corrigan, on another page in this journal, even goes so far as to seek to find the particular pair of asteroids to which the catastrophe has happened.

Ephemeris of Comet *f*, 1892 (Holmes).

		App. R. A.			App. Decl.		log Δ	log *r*	Br.
		h	m	s	°	′			
Jan.	5.5	1	08	08	+ 33	48.8	0.3505	0.4199	0.17
	6.5		09	15		47.3			
	7.5		10	23		46.0			
	8.5		11	32		44.8			
	9.5		12	42		43.6	0.3621	0.4224	0.16
	10.5		13	53		42.6			
	11.5		15	05		41.7			
	12.5		16	18		40.9			
	13.5		17	31		40.3	0.3736	0.4250	0.15
	14.5		18	46		39.8			
	15.5		20	01		39.3			
	16.5		21	17		39.0			
	17.5		22	34		38.8	0.3849	0.4275	0.14
	18.5		23	32		38.7			
	19.5		25	11		38.7			
	20.5		26	31		38.8			
	21.5		27	51		39.0	0.3960	0.4300	0.13
	22.5		29	12		39.4			
	23.5		30	34		39.8			
	24.5		31	57		40.3			
	25.5		33	20		40.9	0.4068	0.4325	0.12
	26.5		34	44		41.6			
	27.5		36	09		42.4			
	28.5		37	34		43.3			
	29.5		39	00		44.2	0.4175	0.4350	0.11
	30.5		40	27		45.3			
	31.5		41	54		46.4			
Feb.	1.5		43	22		47.6			
	2.5		44	50		48.9	0.4279	0.4375	0.11
	3.5		46	19		50.3			
	4.5		47	49		51.7			
	5.5		49	19		53.2			
	6.5	1	50	50	+ 33	54.7	0.4382	0.4400	0.10

Comet *f*, 1892.—The famous comet Holmes (supposed by some to be the last one of Biela) has been observed here on nearly every clear night since we received the telegram announcing its discovery. This object seemed to increase in size rapidly until Nov. 20, and was then apparently traveling rapidly towards the Earth. It was the most brilliant on Nov. 20th and was distinctly visible to the naked eye, being a little to the south of the nebula in Andromeda. The comet had a well defined nucleus and a very large envelope. At times I thought I could see faint traces of a tail on the following side. After November 20th the comet rapidly grew fainter, and is now on moonlight nights quite difficult to find. The comet's right ascension and declination have changed but little since Nov. 9th, the first night it was observed here. FRANK E. SEAGRAVE.

Providence, Nov. 29th, 1892.

Elements of Comet *g* 1892 (Brooks Nov. 18).—From *Science Observer Special Circular* No. 100 we have the following elements and ephemeris of Brooks' last comet, computed by Dr. S. C. Chandler from observations at Cambridge and Cincinnati Nov. 21, 22, 24, 29, 30.

$$\begin{array}{rl} T & = 1893\ \text{Jan. } 7.67258\ \text{Gr. M. T.} \\ \omega & = 81^\circ\ 07'\ 02''.6 \\ \Omega & = 183\ \ 29\ \ 13\ \ .8 \\ i & = 141\ \ 18\ \ 00\ \ .1 \\ \log q & = 0.095144 \end{array} \left.\begin{array}{l} \\ \\ \\ \\ \end{array}\right\} \text{Eq. Nov. 26.5}$$

EPHEMERIS.

Gr. Midnight	App. R A. h	m	s	App. Decl. °	′	log Δ	Br.
1892 Dec. 7.5	13	26	17	+23	23	0.1155	1.79
11.5	13	36	20	27	07	0.0764	2.21
15.5	13	48	49	31	38	0.0354	2.75
19.5	14	05	04	37	05	9.9937	3.41
23.5	14	27	22	43	34	9.9538	4.18
27.5	15	00	24	50	56	9.9191	5.30
31.5	15	51	38	58	36	9.8939	5.66

Ephemeris of Comet *d* 1892 (Brooks Aug. 28).

From Hill's elements as given in A. J. Vol. XII, p. 119, I have computed the following ephemeris:

G. M. T.	App. R. A. h	m	s	App. Decl. °	′	Log. *r*.	Log. Δ.
1893. Jan. 1.5	14	23	4	−38	44	9.9928	0.0123
2.5		28	31	39	5		
3.5		33	57	39	25		
4.5		39	21	39	44		
5.5		44	42	40	0	9.9962	0.0260
6.5		50	0	40	16		
7.5	14	55	15	40	31		
8.5	15	0	27	40	45		
9.5		5	36	40	58	0.0017	0.0395
10.5		10	42	41	9		
11.5		15	45	41	20		
12.5		20	45	41	30		
13.5		25	42	41	39	0.0090	0.0526
14.5		30	34	41	46		
15.5		35	23	41	53		
16.5		40	8	42	0		
17.5		44	50	42	5	0.0179	0.0651
18.5		49	28	42	9		
19.5		54	2	42	13		
20.5	15	58	32	42	16		
21.5	16	2	58	42	19	0.0282	0.0769
22.5		7	20	42	20		
23.5		11	38	42	22		
24.5		15	52	42	22		
25.5		20	1	42	22	0.0396	0.0879
26.5		24	6	42	21		
27.5		28	7	42	20		
28.5		32	5	42	19		
29.5		35	58	42	17	0.0520	0.0981
30.5	16	39	47	−42	14		

O. C. WENDELL.

Harvard College Observatory, Dec. 14, 1892.

Ephemeris of Comet *d* 1892 (Brooks).

From *Astr. Nach.* No. 3131.

Berlin midn.		App. R. A.			App. Decl.		log. *r*	log. Δ	Br.
1893		h	m	s	°	′			
Jan.	8	15	02	19	– 40	43.8	9.9982	0.0374	19.47
	9		07	29	40	56.1			
	10		12	37	41	07.4			
	11		17	41		17.6			
	12		22	41		26.9	0.0052	0.0508	17.73
	13		27	38		35.2			
	14		32	32		42.7			
	15		37	22		49.3			
	16		42	08	41	55.1	0.0138	0.0636	16.07
	17		46	50	42	00.1			
	18		51	29		04.3			
	19	15	56	03		07.8			
	20	16	00	33		10.5	0.0239	0.0757	14.51
	21		04	59		12.6			
	22		09	20		14.0			
	23		13	37		14.7			
	24		17	50		14.9	0.0352	0.0869	13.07
	25		22	00		14.5			
	26		26	06		13.6			
	27		30	08		12.1			
	28		34	06		10.2	0.0474	0.0974	11.78
	29		38	00		07.8			
	30		41	49		05.0			
	31		45	35	42	01.7			
Feb.	1		49	16	41	58.1	0.0604	0.1070	10.61
	2		52	53		54.1			
	3		56	26		49.8			
	4	16	59	55		45.2			
	5	17	03	19		40.2	0.0740	0.1157	9.57
	6		06	39		34.9			
	7		09	55		29.4			
	8		13	06		23.6			
	9		16	14		17.6	0.0879	0.1236	8.66
	10		19	18		11.4			
	11		22	19	41	04.9			
	12		25	16	40	58.2			
	13		28	09		51.3	0.1020	0.1306	7.86
	14		30	58		44.3			
	15		33	44		37.0			
	16		36	25		29.6			
	17		39	03		22.1	0.1163	0.1367	7.16
	18		41	37		14.5			
	19	17	44	08	40	06.8			
	20	17	46	35	39	59.0			
	21		48	58		51.1	0.1305	0.1420	6.54
	22		51	18		43.1			
	23		53	34		35.1			
	24		55	46		27.0			
	25	17	57	55		18.7	0.1446	0.1465	6.00
	26	18	00	01		10.4			
	27		02	05	39	02.0			
	28	18	04	05	–38	53.5			

Meteors of Nov. 23, 1892.—Happening to look up for the comet in Andromeda at $6^h\ 55^m$ P. M., Pacific Standard time, I saw several meteors of short course appearing to radiate from a point very close to the S. E. part of the nebula of Andromeda. In five minutes I saw fifty in the immediate vicinity. I then called three members of a family so as to command the sky to the north, east and partly to the west and also to the southward about ten or twelve degrees from the radiant. We lost five minutes and then continued the count from the first fifty. At $7^h 32^m$ we had counted 300; at $8^h 03^m$, 700; and the eighth hundred was counted in the next seven minutes. I left the observing to the other watchers who reported a total of 1,205 at $8^h 36^m$, with the meteors falling as fast as before. One of the later hundreds was counted in six minutes. Frequently three and four meteors were visible at once, and sometimes five. Many of the meteors were faint with short quick courses, others were bright, about third a second magnitude, with quick courses of five to seven degrees. One very bright one, about first magnitude had a quick course of ten degrees and left a bright trail that lasted fifteen seconds.

One moderately bright meteor blazed out nearly at the radiant with a course only one degree long. A faint one grazed the south side of the nebula. Some few of the courses were apparently curved, and some very decidedly zigzag. The earlier meteors radiated from a point close to the S. E. part of the nebula of Andromeda; at the close of our observations and at 9 o'clock the radiant had a position five or six degrees east of the nebula and about half a degree south.

At 9:10 a few minutes watching satisfied me the shower continued nearly as strong as at 8 P. M. At ten o'clock the numbers were much reduced.

These observations were made at my home near the Observatory; Mr. Chas B. Hill at the Observatory commenced observing the meteors at $7^h 30^m$. He watched only the southeastern heavens and counted 100 meteors in nine minutes. Had there been another observer looking to the southwest, we may reasonably expect that an equal number would have been seen in that direction. The part towards the northwest not commanded by us may be assumed to have shown one-half those seen by Mr. Hill. Combining these four areas there would have been observed 3,600 meteors in the ninety-six minutes of our watching. Many small ones must have been overlooked.

I kept my eyes directed mainly towards the radiant and obtained many minute meteors; those seen low down were generally larger. From 12:05 to 12:35, past midnight, I watched very carefully and saw twenty-two meteors of which two or three were not conformable. It was somewhat difficult to fix the radiant but it was not less than eight degrees east of the nebula of Andromeda and probably one degree south. A few of the meteors were small, but the most were about the second or third magnitude. All the courses were quick and three to five degrees long. I commanded a limited region about the radiant. One meteor exhibited half a dozen bright points immediately behind it and thence further was the usual luminous streak. All meteors leave an impression upon me that they are high up in the atmosphere but at 12:30 one crossed just above what I had decided was the radiant: it had no visible head and was a rather faint streak of light with much swifter movement than any other of this shower through a course fifteen degrees long, and it left the decided impression that it was very close to the Earth.

The whole evening was very clear and stars of sixth magnitude were easily visible.

Through the evening of the 24th I watched at intervals until midnight but saw only a few meteors non-conformable to the radiant of those of the 23rd. The 25th was quite hazy and only the second and third magnitude stars visible but no meteors. 26th. Heavy clouds. 27th. Southeastern a few openings about 11 P. M. but no meteors were seen. GEORGE DAVIDSON.

Davidson Observatory, San Francisco, Cal.

Meteors of Nov. 23, 1892.—A great meteoric shower was observed here on Wednesday evening the 23d. The shower commenced here about nine o'clock and lasted until nearly midnight. Between ten and eleven o'clock over four hundred meteors were counted. Instead of radiating from Andromeda they seemed to radiate more from the great square in Pegasus. Most of these meteors moved in a north and northwesterly direction. On the nights of November 27th and 28th the meteors were few here, and none of any great brilliancy were seen. Possibly the fragments of Biela's comet are due early every revolution.

Providence, Nov. 29th, 1892. FRANK E. SEAGRAVE.

Solar Eclipse of Oct. 20, 1892.—This eclipse was observed at the Chamberlin Observatory with the 6-inch equatorial, equipped with a polarizing solar eyepiece, and a magnifying power of 200 diameters.

At the first contact the definition was fair, but the Sun's limb was trembling somewhat. The notch was surely seen: the serrations of the Moon's limb were very marked. At the last contact the Sun's limb was more disturbed than at the first, but yet the observation was accounted satisfactory. The times were noted by the eye and ear method. At times during the eclipse the cusps were very sharply defined; there was nothing to suggest the suspicion of a lunar atmosphere.

Miss Edna Iliff observed the last contact with a five-inch Clark glass, equipped with a Herschel solar eyepiece, the magnifying power being 61 diameters. She recorded the time on the chronograph. The local mean times are given.

		Ch. Obs. M. T.			Observer.
First Contact	Oct. 19	21^h	50^m	$52^s.5$	H. A. H.
Last Contact		23	53	42 .6	H. A. H.
Last Contact		23	53	37 .5	E. I.

Denver, Colo. HERBERT A. HOWE.

Seven New Asteroids.—The superiority of the photographic over the old method of discovering new asteroids is well shown by the number discovered in November by the new method, at Heidelberg and Nice. 1892 L was found in November on plates which were exposed August 23 and 29 by Dr. Wolf at Heidelberg. It was observed by Palisa at Vienna, Nov. 22, being found by the aid of a circular orbit which Dr. Berberich calculated from the photographed positions. The following is the list of photographs and first positions:

	Photograph.				First Position.								
1892.	By	At	Date	Mag.	Gr. M. T.			App R. A.			Decl.		
						h	m	h	m	s	°	′	″
L	Wolf	Heidelberg	Aug. 22, 29	13.	Aug. 22	12	05	23	23	53.5	— 7	03	32
M	Charlois	Nice	Nov. 15, 16	11.5	Nov. 20	6	03	2	12	28.4	+ 10	02	09
N	Wolf	Heidelberg	Nov. 15, 20	——	Nov. 15	9	37	4	10	34.6	+ 23	34	49
O	Charlois	Nice	Nov. 23, 24	11.0	Nov. 24	7	47	2	47	43.3	+ 10	12	10
P	Charlois	Nice	Nov. 25	11.0	Nov. 27	7	08	3	37	47.9	+ 11	27	53
Q	Charlois	Nice	Nov. 28	12.0	Nov. 29	7	39	3	50	54.1	+ 12	23	37
R	Charlois	Nice	Nov. 28	12.5	Nov. 29	8	03	3	59	30.7	+ 13	29	10

Transit of Mercury, May 9, 1891.—As observed at the Davidson Observatory, San Francisco, Cal., Latitude = 37° 47′ 24″.1; Longitude = $8^h\ 09^m\ 42^s.75$.

Observer, Professor George Davidson, U. S. Coast and Geodetic Survey, using the 6.4-inch Clark equatorial (reduced to 4¼-inches) with eye-piece magnifying 130 diameters, and double wedge of colored glass showing Sun white. Sidereal chronometer No. 3479, fast of local sidereal time 33.56 seconds.

I contact = $6^h\ 54^m\ 04^s.2$ by chronograph. Observation good. No sign of Mercury for three minutes before I, although looking at exact spot of contact.

II contact = $6^h\ 58^m\ 24^s.5$ by chronograph. Limbs very unsteady. No light interval between limbs. Black drop. Time not close on account of the atmospheric unsteadiness. I assume this time to represent the geometrical contact.

$6^h\ 58^m\ 51^s$ by chronometer: absolutely wide opening between the limbs of Sun and planet.

Observer, Mr. F. W. Edmonds, using Hassler equatorial 3-inches aperture-eye-piece magnifying 60 diameters. Sidereal chronometer No. 211, slow of local sidereal time = $13^m\ 52^s.13$:

I contact, lost.

II contact = $6^h\ 44^m\ 16^s.5$ by chronograph.

Observer, Mr. T. D. Davidson, using 3-inch Fraunhöfer, power 60 diameters. Mean time chronometer No. 5038, fast of local mean time $5^m\ 43^s.10$:

I contact, lost.

II contact = $3^h\ 54^m\ 00^s$ by chronograph.

Observer, Mr. A. P. Redington, using 3-inch Clark, power 60 diameters, sidereal chronometer No. 380 slow $2^h\ 38^m\ 22^s.75$ of local sidereal time:

I contact, lost (first seen $4^h\ 16^m\ 04^s$ by chronograph).

II contact = $4^h\ 19^m\ 50^s$ by chronograph.

Observer, Mr. Chas. B. Hill, using private 6 inch equatorial of Captain Chas. Goodall, situated 45″.0 south and $1^s.7$ west of the Davidson Observatory, (or in Latitude 37° 46′ 39″.1; Longitude $8^h\ 09^m\ 44.4^s$). Solar prism and mean time chronometer No. 231, fast of Davidson Observatory mean time = $2^s.37$:

I contact = $3^h\ 44^m\ 13^s$ by chronometer. First seen when well on (estimated 20^s) wind shaking building and telescope violently, image continually oscillating four and five minutes of arc. Power 65 diameters.

II contact, $3^h\ 47^m\ 43^s$ close to contact; $3^h\ 48^m\ 01^s$ certainly past. The two times of contact are two epochs of fairly distinct vision and limit the true contact. I take the mean as the best possible under the circumstances. Wind continually jarring telescope and observation well-nigh impossible. Power 130 diameters.

The local time was determined by Mr. Hill at the Davidson Observatory on the evenings of May 7, 8 and 9. The chronometers were compared before and after the transit by Mr. Edwards, and the rates of the standard chronometer and sidereal clock agreed at the time within five one-hundredth seconds.

A summary of the observations is given in a table below:

Observer.	I CONTACT.		II CONTACT.	
	Local Sidereal Time.	Pacific Standard Time	Local Sidereal Time.	Pacific Standard Time.
	h m s	h m s	h m s	h m s
G. Davidson	6 53 30.6	3 53 13.3	* 6 57 50.9	3 57 32.8
F. W. Edmonds	……	……	6 58 08.6	3 57 50.5
T. D. Davidson	……	……	6 58 17.8	3 57 59.7
A. P. Redington	……	……	6 58 12.7	3 57 54.6
C. B. Hill	** 6 53 50.7	3 53 33.4	6 57 50.5	3 57 32.4

* Geometrical Contact, wide opening, 26.5^s later.

** Estimated from first view 20^s later.

Occultation of *o* Piscium, Nov. 30, 1892.—The immersion was observed by Miss Lottie Waterbury with the 6-inch equatorial of the Chamberlin Observatory, the magnifying power being 96 diameters. I noted the time for her with a sidereal chronometer. The emersion was noted by Miss Edna Iliff, using a five inch Clark glass, equipped with a magnifying power of 80. The definition was superb, and the star was seen without difficulty. The time of emersion was noted on the chronograph. Both are local mean times.

Immersion..................	4^h	38^m	$45^s.1$
Emersion....................	5	12	18 .3

H. A. HOWE.

NEWS AND NOTES.

This number is sent to some subscribers who have not ordered a renewal of subscription for 1893. It is especially hoped that all orders will be promptly made that the lists for the new yearmay be correct before the close of the present month.

It is a most encouraging fact that the subscription list to this publication increased, during the last year, more than twenty per cent. This, with other signs of possible progress, has led the Editors to seek new and most efficient help for their regular work indicated by the names of the staff on the first cover page. Still another name or names will be added later on. No pains will be spared to secure best results possible for 1893.

One of the most serious hindrances in our work in the past has been, the difficulty we have met in obtaining late important news from the observatories of the United States. This is not because astronomers are not interested in their own work, or the work of others for if we go wrong in regard to notices of either or in any other way we promptly hear from them, generally with the kindest reminders possible, but sometimes we have been criticised most unmercifully. Now, this is proof positive of unusual and unabated interest in what is for the good of our science and its workers. Would it not be a good idea for every astronomer in this country to contribute some brief note or item of general interest for every issue of this publication for this year? We will try to give space for such a summary of current astronomical intelligence in every number in the future.

The Planet Mars.—M. Flammarion has recently published a most interesting and valuable monograph entitled "La Planète Mars et ses conditions d'habitabilité." The author has endeavored to collect into one volume all the information which is to be obtained from all the observations which have been made up to the present time. The volume is illustrated with nearly 600 copies of drawings and 23 charts of the planet. It is interesting to look over these drawings and note the gradual increase in accuracy and amount of detail seen with the improvement of the telescope. The first drawings we find are those of Fontana in 1636 and 1638. These show no detail on the surface of the planet. The markings shown are evidently due to optical defects in his telescope. The first really good drawings which we find are those of Father Secchi made at Rome in 1858 with a 9-inch refractor.

It would be impossible to give a complete review of the work here. It will suffice to say that the author, having collected all the available observations up to, and partly including 1892, gives a careful discussion of the material, treating of the surface conditions, climate, seasons, conditions of habitability, etc., in a manner which makes the book pleasant reading, and so completely as to make it invaluable as a source of information concerning the planet.

Astronomy, Physics and Chemistry in Primary and High Schools.—At its last annual meeting the National Educational Association raised a committee of ten with President Eliot, of Harvard University, as Chairman, to consider ways and means by which a uniform preparation for College and University may be secured in secondary schools in the United States. Ten persons selected from different parts of the United States have been asked to serve on each of nine different topics, one of which is "Astronomy, Physics and Chemistry." The persons selected for this committee are as follows:

Professor Brown Ayres, Tulane University, New Orleans, La.
Irving W. Fay, The Belmont School Belmont, Calif.
Alfred P. Gage, English High School, Boston, Mass.
Professor William W. Payne, Carleton College, Northfield, Minn.
W. C. Peckham, Adelphi Academy, Brooklyn, N. Y.
William McPherson, Jr., 2901 Collinwood Ave., Toledo, O.
Professor Ira Remsen, Johns Hopkins University, Baltimore Md.
Professor James H. Sheppard, South Dakota Agricultural College, Brookings, So. Dak.
Professor William J. Waggoner, University of Colorado, Boulder, Colo.
George R. White, Phillips Academy, Exeter, N. H.

This committee is to meet in Chicago, Cobb's Hall, Chicago University, December 28, for the discussion of a series of questions suggested by the general committee before referred to. When the report of the committee is completed, it will be published, for we anticipate some important changes will be advised in regard to teaching these branches in Secondary and Primary schools.

Double Star Observations.—Mr. W. H. Maw publishes in the Memoirs of the R. A. S., Vol. L, his double star observations during 1888-91, the reprint of which we have just received. The measures were made with a 6-inch Cooke refractor and filar micrometer, and appear to be very accurate. The list of 153 stars consists mostly of the doubles discovered by Σ and *O*Σ but includes some of Burnham's close pairs.

Publications of the Cincinnati Observatory No. 12—This is a most valuable catalogue of 1340 stars having proper motions greater than 0.15″, by J. G. Porter, the Director of the observatory. Professor Porter has collected all the available observations of each star and has re-observed with the new Meridian Circle all except those which were too far south in declination. All the observations have been reduced to the epoch 1900 and published in convenient form for reference. Except in the case of the Berlin Jahrbuch stars the proper motions have all been determined anew. We notice a large proportion of 8th to 9th magnitude stars, the motions of which, from a cursory examination, do not appear to be less than those of the brighter stars At the end of the publication is given a catalogue of the resulting positions for 1900, together with the precession, secular variation and proper motion in right ascension and declination. We miss, however, a list of the proper motions reduced to the arc of a great circle. Such a list would be very useful in comparing the motions of stars of different magnitudes.

On page 764, November number of ASTRONOMY AND ASTRO-PHYSICS Professor Porter gives the results of a new determination of the Solar Motion from these stars.

Publications of the Observatory of Lyons.—The latest publication of the Observatory under the direction of M. Ch. André is a memoir entitled "Recherches sur l'Équation Personelle dans les observations astronomiques de passages" by M. F. Gonnessiat. This is an important research, and M. Gonnessiat appears to have carried it out very thoroughly. In the Memoir he gives a complete history of all previous investigations of personal equation and works over a good deal of the material obtained in them as well as in his own. He finds, as was to be expected, that the systematic errors of the electric method of registering time are much less liable to variation and have a smaller range than those of the eye and ear method. In searching for the cause of personal equation he finds that in the eye and ear method they may be considered as four:

1. The rythm of beats in counting time (*rythmic equation*).
2. The persistance of the luminous impression on the retina (*physiological equation*).
3. The lack of co-ordination of two different perceptions (*psycho-physiological equation*).
4. The tendency to estimate fractions of seconds in a systematically erroneous manner, (*decimal equation*).

In the electrical method the author divides the causes as follows:

1. The lack of apparent coincidence between the axis of the wire and the center of the star at the instant when the observer decides to press the key, (*equation of bisection*).
2. The persistance of the luminous impression, (*physiological equation*).
3. The time that it takes the impression received by the eye to determine the action of the muscles of the hand. (*psycho-physiological equation*).

The author attempts to give the limiting values of the errors which may be produced by these causes in the following tables:

Eye and Ear Method.

	s		s
Rythmic equation	—0.15	to	+ 0.30
Physiological equation	—0.05	to	+ 0.00
Psycho-physiological equation	—0.15	to	+ 0.05
Decimal equation	—0.05	to	+ 0.05
Limits of total equation	—0.40	to	+ 0.40
Difference of extremes		$0^s.80$	

Electric Method.

	s		s
Equation of bisection	—0.10	to	+ 0.10
Physiological equation	—0.05	to	+ 0.00
Psycho-physiological equation	—0.20	to	+ 0.05
Limits of total equation	—0.35	to	+ 0.15
Difference of extremes		$0^s.50$	

We have received, at the same time with the above publication, three volumes "of Meteorologie Lyonnaise" for the years, 1887-90. H. C. W.

Editor Astronomy and Astro-Physics:—I am computing the orbit of the double star 70 Ophiuchi, and if any of your readers know of unpublished measures of this star, or of measures that I should not be likely to find, I should be pleased to hear from them. To those who are interested I will gladly send a list of the measures that I have at present. A. D. RISTEEN.

P. O. Drawer S, Hartford, Conn.

To the Editor of Astronomy and Astro-Physics.—Sir: May I ask leave to make one or two remarks on some papers in your issue of November?

Professor Coakley does not seem to have seen Professor H. A. Newton's paper on meteorites in which the author endeavors to discover the nature of their orbits from the phenomena attending their fall. He concludes that they were most probably moving round the Sun in orbits of short period when they encountered the Earth. This theory of course leaves the question whether any of these bodies have come to us from outside the solar system (as assumed by Mr. Lockyer) undecided. Professor Coakley's view would deprive much of the meteoritic theory of its basis.

With respect to Professor Porter's article on "The motion of the Solar System," I wish to remark that I believe small proper motions are largely affected by errors of observation and computation and cannot be relied on for the purpose. I have lately been examining the Pulkova Catalogue and I find an enormous preponderance of proper motions in diminishing right ascension. Even between 18^h and 6^h where the Sun's motion tends to increase the R. A. this preponderance exists though the amount is diminished. Such a preponderance seems to me impossible if the length of the year is rightly computed and there is no error in the amount of precession. We have no similar test for proper motions in declination but it seems probable that they are affected by similar errors. When we are dealing with large proper motions small errors are of little consequence but it is quite otherwise when these motions are small. The slight corrections introduced by Herz and Strobl into Auwers' Catalogue have in many cases changed even the direction of a small proper motion. Truly yours,

W. H. S. MONCK.

Erratum p. 844, line 8, for "Clyton" read "Clifton."

A Monster Telescope.—It seems to be a serious proposition, which we were inclined to doubt when we heard of it through the newspapers, that has been made in Paris, to construct a gigantic reflecting telescope, the mirror of which is to be 10 feet in diameter and the length of the tube 140 feet. It is to be ready for the Exhibition, which is to be held in Paris in 1900. The mirror is to be silver-on-glass. Mr. A. A. Common, in *The Observatory* for November, 1892, discusses some of the difficulties of construction and suggests some modifications of the ordinary form of mounting, to meet the purposes for which this great instrument is evidently intended.

M. Trepiéd, Director of the Observatory of Algiers, also (*Ciel et Terre* Nov. 1, 1892) discusses the magnifying power of such an instrument. The French papers, in announcing the project, made the statement that this instrument would bring the Moon within one metre. M. Trépied shows that with the highest practical power, in the best atmosphere, the Moon would be seen as if it were 25,000 metres or 15 miles distant.

Silvering Glass Mirrors.—Some years ago I had occasion to silver several glass mirrors, and in doing this, I followed a process given in the *Chemical News* for March, 1869. I was inexperienced at that time in all kinds of chemical manipulations, and although the mirrors were not large, the success which attended my work was such as to lead me to receive the statement of the article in the December number of ASTRONOMY AND ASTRO-PHYSICS "that hard-and-fast rules cannot be laid down" with some qualifications.

The process which I employed was given in the *Chemical News* as "Mr. Browning's process." I presume that the directions, as I have them now, were not copied verbatim, but they have all essential points. I worked at any convenient temperature without experiencing difficulty. I give the directions below.

Prepare three standard solutions. (A) Crystals $AgNO_3$, 90 gr., H_2O, 4 oz. (B) Potassa, pure by alcohol, 1 oz., H_2O, 25 oz. (C) Milk sugar powder, ½ oz.-H_2O, 5 oz. This (C), must be prepared fresh at time of using.

Pour 2 oz. solution (A) into a vessel holding 35 oz. Add ammonia, stirring constantly till a clear solution of the precipitate first thrown down is obtained. Add 4 oz. solution (B). Add ammonia just sufficient to redissolve precipitate. Add water till the bulk reaches 15 oz. Add drop by drop solution (A) till a grey precipitate is formed which does not dissolve after three minutes stirring. Add 15 ounces more distilled water. Let it settle. Do not filter. When the mirror is ready, add 2 oz. solution (C) and stir throughly. (Solution (C) may be filtered).

Cement pieces of cork to the back of the mirror as handles. Pour on the surface strong nitric acid and rub it all over with a brush made by plugging a glass tube with pure cotton wool. Clean thus thoroughly the surface and edges, wash well with common water, and then with distilled water, and then lay face downward in spirits of wine (strong) till silvering fluid is ready.

Immerse the mirror face down in solution, so that it may rise about one-eighth of an inch on the edges, avoiding bubbles beneath. Let it remain an hour or two. Then wash immediately with a large quantity of water, then with distilled water. Place on edge on absorbent paper to drain and dry. Polish with gentle rubbing with softest wash leather. Finishing with same dusted with thoroughly dried rouge obtained by stirring rouge in water, pouring off what does not settle in fifteen minutes, and collecting in filter.

My principal difficulty was in cleansing the mirror. I found it advantageous to use strong nitric acid, strong ammonia, and water in succession several times, ending with distilled water, and immersion in alcohol. The difficulty in this was a resulting elevation of temperature requiring that the water be not cold, or the changes of temperature loosened the cemented handles. Obviously heavy mirrors would require special precautions and widely different methods of support.

A very little tartrate of copper proved a desirable addition to the silver solution. I have no record of the proportion added, but it was very little.

CHAS. H. CHANDLER.

Chicago Academy of Sciences, Section of Mathematics and Astronomy.—The regular meeting of the Section was held at the Kenwood Observatory on Tuesday evening, Dec. 6th, 1892. Mr. Douglass presided.

Mr. S. W. Burnham read a paper on astronomical observations with large telescopes. After describing some of the larger refracting and reflecting telescopes Mr. Burnham discussed the relative merits of large and small instruments, concluding that other things being equal the size of a telescope is a direct measure of its power and usefulness. Certain writers have recently attempted to show that large telescopes have not proved wise investments, and that no work has been done with them which could not have been equally well performed with smaller apertures. Such statements Mr. Burnham characterizes as absurd. The satellites of Mars and the recently discovered satellite of Jupiter could never have been found with small instruments, and many double stars discovered with the 36-inch on Mt. Hamilton have not been recently measured simply because they are beyond the reach of all other telescopes. It is true that with some large telescopes not much has been accomplished, but this is the fault of the observer and not of the telescope. In light, resolving power and every other important factor large apertures are much superior to small.

In answer to a question Mr. Burnham expressed his approval of a site near Chicago for the 40-inch Yerkes telescope. He considers that if the new observatory is placed within fifteen or twenty miles of the city it will be as advantageously situated as any other observatory in the United States, with the single exception of the Lick Observatory. The latter enjoys a larger proportion of clear nights, but it is not certain that the best seeing at Mt. Hamilton is much superior to the best seeing at Chicago.

Professor Henry Crew prefaced his paper on recent investigations in the infra-red and ultra-violet spectrum by a review of the researches in this field of Herschel, Becquerel, Abney, Langley and others. He dwelt at greater length on Snow's recent studies of the infra-red spectra of the alkalies, and pointed out the interesting confirmations of Kayser and Runge's predictions from theory as to new lines in the spectra of these substances. Schumann's important photographic investigations in the extreme ultra-violet hydrogen spectrum were next discussed, and reference made to the additions made at the Kenwood Observatory to the number of known lines in the rythmical spectrum of hydrogen. The paper concluded with an account of the studies of Hertz and others on electrical waves. Throughout the paper the illustration recently described by Stoney in the Philosophical Magazine was employed, in order to give a tangible idea of the magnitudes of the minute quantities under discussion.

Professor George E. Hale followed with a short review of attempts which have been made by various astronomers to photograph the corona without an eclipse, and described a new apparatus which he has devised for the same purpose. The method is a modification of that employed by Dr. Huggins, and it is hoped that it may soon be put to a practical test.

A number of photographs of the Moon and various solar phenomena from negatives made at the Kenwood Observatory were shown on the screen and explained, after which the meeting adjourned. GEORGE E. HALE, Recorder.

Astronomical and Physical Society of Toronto.—It is a matter of no little pride to notice the steady growth and interest manifested in the meetings of the Astronomical and Physical Society of Toronto, as the proceedings of the same are published regularly in those excellent daily papers, "The Globe" and the "Toronto Enterprise." These full reports enable the friends of this young society, far and near, to know very particularly what the many active members are doing in study and observation. We have been greatly interested in all the work so far prosecuted and have arranged to give, in the future, fuller reports in this publication than we have been able to do in the past for the want of space. The very complimentary notices of ASTRONOMY AND ASTRO-PHYSICS that appeared in the "Toronto Enterprise," Dec. 17 and in "The Globe" of Toronto, Dec. 19, are favors most highly appreciated.

BOOK NOTICES.

A Treatise on Plane and Spherical Trigonometry and its applications to Astronomy and Geodesy, with numerous examples, by Edward A. Bowser, LL. D., Professor of Mathematics and Engineering in Rutgers College. Boston: Messrs. D. C. Heath & Co,, Publishers.

Until now we have not had the pleasure of seeing a copy of the Trigonometry recently published by Professor Bowser. This book presents a very full course of study, and it is intended to be varied and complete enough for use in the best technological schools. The examples illustrate every part of the subject, and are chosen to test, not only the student's knowledge of the usual methods of computation, but also his ability to grasp them in the various forms they may assume in practical applications. The fourteen pages given to the solution of trigonometrical equations is a noteworthy feature, and the chapters on De Moivre's Theorem, Astronomy, Geodesy and Polyhedrons will certainly serve to introduce the student to some of the higher applications of Trigonometry not usually found in American text-books. The attention of students and teachers of Trigonometry is called to Professor Bowser's new work as one also suitable for reference in matter of principle, method and especially examples for illustration.

PUBLISHERS' NOTICES.

The subscription price to ASTRONOMY AND ASTRO-PHYSICS in the United States and Canada is $4.00 per year in advance. For foreign countries it is $4.40 per year which is the uniform price. Messrs. Wesley & Son, 28 Essex Street, Strand, London, are authorized to receive subscriptions. Payment should be made in postal notes or orders or bank drafts. Personal checks for subscribers in the United States may be used.

Currency should *always* be sent by registered letter.

Foreign post-office orders should *always* be drawn on the post-office in Northfield, Minnesota, U. S. A.

All communications pertaining to Astro-Physics or kindred branches of physics should be sent to George E. Hale, Kenwood Observatory, of the University of Chicago, Chicago, Ill.

For information of correspondents, the names and addresses of the associate editors of ASTRO-PHYSICS are given as follows:—

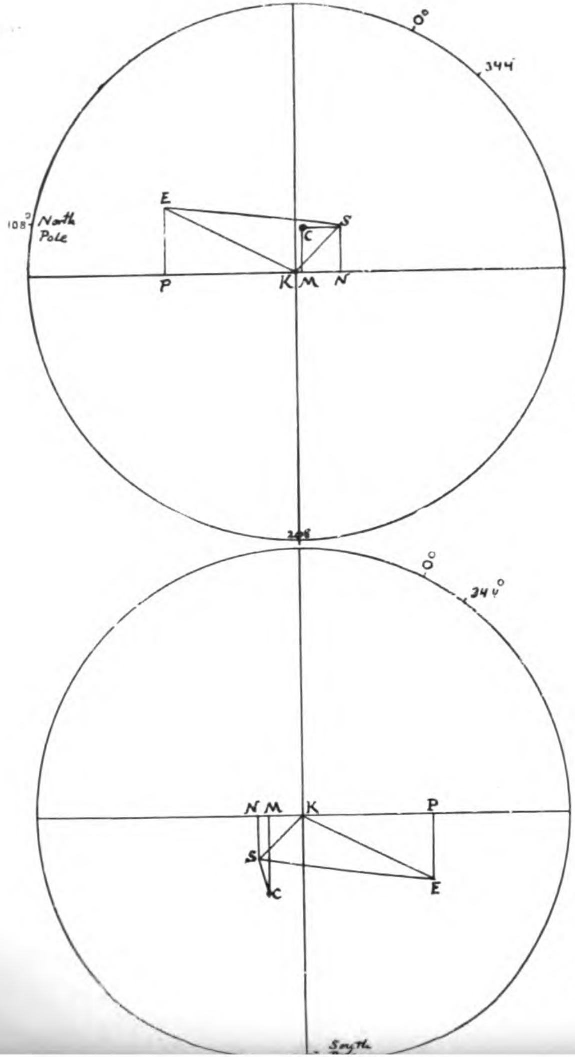
James E. Keeler, Observatory, Allegheny, Pa.; Henry Crew, Northwestern University, Evanston, Ill.; Joseph S. Ames, Johns Hopkins University, Baltimore, Md.

All matter or correspondence relating to General Astronomy, remittances, subscriptions and advertising should be sent to Wm. W. Payne, Publisher and Proprieter of ASTRONOMY AND ASTRO-PHYSICS, Goodsell Observatory of Carleton College, Northfield, Minn.; and the Associate Editors for General Astronomy are: S. W. Burnham, Government Building, Chicago Ill.; H. C. Wilson, Goodsell Observatory, Northfield, Minn.

Manuscript for publication should be written on one side of the paper only and *special care should be taken to write proper names and all foreign names plainly*. All drawings for publication should be *smoothly* and *carefully* made, in *India Ink* with lettering well done, because such figures are copied exactly by the process of engraving now used. If drawings are made about double the size intended for the printed page, better effect will be secured in engraving than if the copy is less in size. It is requested that manuscript in French or German be typewritten. If requested by the authors when articles are sent for publication, *twenty-five* reprint copies, in covers, will be furnished free of charge. A greater number of reprints of articles can be had if desired, at reasonable rates.

Rates for advertising and rates to news agents can be had on application to the publisher of this magazine.

PLATE XIV.



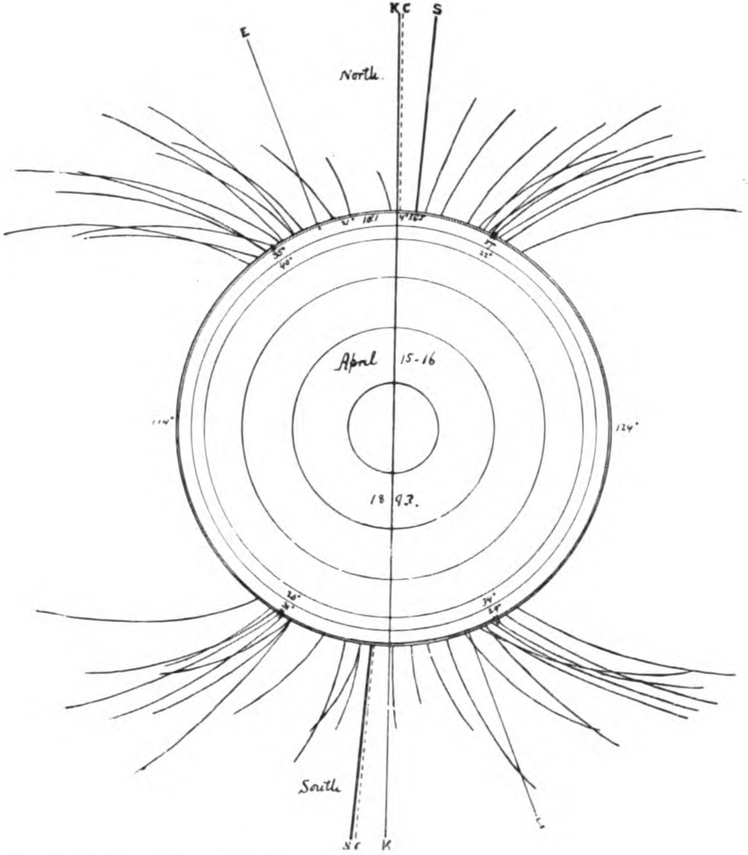


Plate accompanying Professor Bigelow's Paper.

Astronomy and Astro-Physics.

VOL. XII, No. 2. FEBRUARY, 1893. WHOLE No. 112

GENERAL ASTRONOMY.

PREDICTION REGARDING THE SOLAR CORONA OF THE TOTAL ECLIPSE OF APRIL 15-16, 1893.*

FRANK H. BIGELOW.

I shall venture to make the following prediction regarding the position of the corona of April 15-16, 1893, as seen by an observer on the Earth, including also the places of the coronal poles, and the relative distribution of the stream lines in the corona itself. Using the following notation and elements:

N, the ascending node of the Sun's equator on the ecliptic, 74°.

I, the inclination of these planes, 7° 15′.

W, the inclination of the Earth's orbit, 23° 27′.3, we have,

L, the heliographic longitude of the Earth or center of disk, 313° 2′.5.

D, the heliographic latitude of the Earth or center of disk, — 5° 18′.7.

If K is the pole of the ecliptic,
S the pole of the Sun's axis,
E the pole of the Earth's axis,
C the pole of the corona,

and their projections on the plane perpendicular to the line of vision, passing through the center of the Sun, K, N, P, M, respectively, and if O is the apparent center of the disk, then the angles,

$$\begin{aligned} H &= KOS = 4^\circ\, 56'.5, \\ G &= EOK = 21^\circ\, 10'.1, \\ \text{and } H + G &= EOS = 26^\circ\, 6'.5. \end{aligned}$$

Co-ordinate angles from the Sun's axis being taken as positive in both hemispheres towards the west, and negative towards the east; as positive on the earthward side of the plane of projection, and negative on the opposite side, the co-ordinates of the coronal poles referred to the plane passing through KO, perpendicular to the line of vision; and to the plane through SO, including the line of vision, will be:

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* Communicated be the author.

for the north coronal pole, NM $= -4\frac{1}{2}°$, east,
MC $= -5°$, back;
for the south coronal pole, NM $= +1°$, west,
MC $= +8\frac{1}{2}°$. front.

Hence the heliocentric longitude of the Earth being 208°, that of the north coronal pole will be 108°, and that of the south coronal pole will be 214°, approximately.

The following diagram results from projecting orthogonally the north polar regions of the Sun downwards upon the plane of the ecliptic, and the south polar regions upwards upon the same plane.

The diagram of the stream lines in the corona is obtained by projecting the shadow of the model of the Sun and its corona, already described, upon a screen, after it has been placed in position by the following data, due to a method not yet published. Take June 12.22, 1887, as the epoch when the south pole of the corona is in the plane passing through the centers of the Sun and the Earth perpendicular to the Ecliptic, and between the Earth and the Sun, then the synodic period 26.68 days gives April 15.60, 1893, as the next preceding recurrence before the eclipse. The diagram explains itself quite clearly so that a description of it is not needed here. The figures on the outer circle are the angles, counted from the axis K, to the middle of the bunch of overlapping stream lines superposed in projection, those on the inner circle referring to the axis S. In pictures of the corona, these concentrations appear as the quadrilateral projections, and will not generally show individual stream lines. Such rays as are separated from each other, for the most part cluster around the poles within these bunches, although sometimes a line or two can be made out on the equatorial side of them.

The diagram cannot hope to represent the exact lines that may appear at the eclipse, for obvious reasons, but it may succeed in showing the general distributions of the lines as regards the poles of the Sun or of the ecliptic. Thus, the compressed side of the corona is eastward, and the open side westward of the disk of the Sun; the N. E. quadrant should appear thin and short, but the N. W. fuller and longer as to its lines, the two southern quadrants being more symmetrically disposed.

I fear that at the eclipse of 1893 the conditions of solar output will be so intense as to obscure the lines entirely, because the only photographs of the corona that are available for measures were secured at times of the minimum eruptive energy of the Sun, namely in 1878 and 1889. I shall look on that date, April 16, 1893, also for spottedness of the Sun's surface above the average for magnetic and auroral disturbances, and for marked changes in the barometric pressures from high to low throughout the northern hemisphere.

It should be remarked that the data thus furnished are more a test of the accuracy of my epoch and period of rotation of the Sun than of the theory of its physical constitution that I have advocated in earlier papers on the corona.

In order to obtain valuable photographs of the stream lines of the corona for measurements it is essential that the telescope used have a long focus, more than ten feet if possible; also it is shown by experience that all such good pictures have been taken with rather short exposures, usually under three seconds; and furthermore the best emulsions for holding the inner and the outer regions of the corona, without burning the inner parts, have been made with collodion and not with gelatine.

NOTE ON THE PROBABLE ORIGIN OF HOLMES' COMET.*

SEVERINUS J. CORRIGAN.

In quest of the identity of the celestial bodies which have, probably, been in collision and thereby produced Holmes' comet according to the hypothesis which I have enunciated in No. 111 of ASTRONOMY AND ASTRO-PHYSICS, I have completed the examination of the list of those asteroids whose elements have been determined, whose number now exceeds three hundred.

The process of examination was very simple. I assumed that the *hypothetical* collision occurred on, or shortly before, the date of discovery, Nov. 6, 1892.

In support of this assumption I adduce the fact that this comet when discovered was of such considerable dimensions and brightness, that it surprised the discoverer, who had examined the same immediate region of the heavens in which this body was discovered, only twelve days before he found the latter, without seeing anything that would indicate the approach of so conspicuous an object, a fact which cannot be accounted for by the hypothesis of a rapid approach of the comet to either the Sun or the Earth, because the elements clearly show that on Nov. 6 and thereafter, it was receding from instead of approaching both those bodies.

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* Communicated by the author.

Furthermore the rapid expansion of the volume of the comet, shortly after the time of discovery, indicates very clearly that the catastrophe could not have occurred *very* long before that time.

From the elliptic elements computed by Rev. Geo. M. Searle, and given in the last number of this magazine, I have found that the radius vector of this comet was on Nov. 5.0, approximately, 2.286, the heliocentric longitude nearly 35°, and the heliocentric latitude about + 18°. The next step was, obviously, to find if possible, such of the known asteroids whose radii-vectores and heliocentric longitudes and latitudes were the same, or nearly the same, on Nov. 5.0, 1892, as those of the comet on the same date.

The well-known relation between the longitude, l, the latitude, b, the inclination, i, and the node, Ω, expressed by the equation, $\tan b = \tan i \sin(l - \Omega)$, furnishes one criterion by which the question of the retention or rejection of any asteroid as a possible component of the comet, can be rapidly decided. In the first place, it is plainly apparent that no asteroid whose inclination lies below about 18°, is admissible; therefore, a large majority of those on the list were rejected on mere inspection.

Furthermore, the equation shows that for each inclination above 18°, there must be two definite positions (corresponding to the angle $(l - \Omega)$ and to its supplement) which the node of any asteroid must occupy in order that such body could be, at any time, at the point where the comet was on Nov. 5.0, and where the collision is assumed to have occurred. This condition caused the rejection of a majority of the bodies retained after the first inspection. Only the computation of the heliocentric longitude and latitude and finally of the radius-vector of each of the very few residual asteroids, was then necessary to complete the examination, the result of which was negative; no asteroids were found that fulfilled all the necessary conditions. If the known asteroids constitute the entire group, this result would be fatal to the hypothesis which I have advanced. But there is sufficient evidence to demonstrate that the number of these bodies cannot be limited to any small amount. If the number discovered decreased with each succeeding year, we might infer a quite moderate limit, but the discoveries have gone on from year to year, with frequency quite undiminished; therefore, the limit of the numbers must be very great.

Furthermore, it is reasonable to suppose that the vast space between the orbits of Mars and of Jupiter should contain much matter, if not in the form of a considerable planet at least in that of a group of small planetary bodies, such as the asteroids are known to be.

Now, while the diameter of the smallest known asteroid cannot be well determined by actual measurement, yet judging by magnitude, and the ordinary light reflecting power, it is probably below 20 miles, and very likely much below that amount. Therefore, it would require more than 9,000,000 of such masses to constitute a body equal even to the small planet Mars. Of course, I do not mean to say that there are that many asteroids, but only to show that their number is probably very great. I think that it will not be considered unreasonable to assume that the number of smaller asteroids, quite beyond the reach of the telescope, may be reckoned by tens of thousands. I would liken the whole group of these bodies to the rings of Saturn which are probably composed of a vast number of minute satellites.

Admitting, therefore, that the number of undiscovered asteroids is very great as compared with those discovered and whose elements are known, it is at once apparent that the *probability* that the component bodies, forming the comet, were *undiscovered* asteroids is, practically, equivalent to a certainty. Therefore, while the negative result of my examination of the list of the known members of the group diminishes the probability of the truth of the hypothesis which I have advanced in regard to the origin of Holmes' comet, the diminution is so small that this hypothesis is not materially affected thereby; the only consequence is that it must ever remain a hypothesis pure and simple.

The probability of its truth must depend upon the fact that the cometary elements are such that they might well represent those of a member of the asteroid group, and upon the further fact that under no other hypothesis can the anomalous phenomenon of an increasing apparent diameter and an increasing geocentric distance be so rationally and satisfactorily explained. True, it might, with some show of reason, be conceived that this comet is the result of the *explosion* of a single asteroid, but the difficulty of determining the probable cause of such an explosion would be much greater than that of the original problem; the supposition of a collision is much more tenable. Theoretically, even such a catastrophe must be one of extreme infrequency, and this is illustrated by the fact that in the whole history of astronomy no such peculiar phenomena as those connected with the Holmes' comet, have been noted. There is also naturally suggested, in this connection the kindred hypothesis that some of the comets of short period, notably Faye's, D'Arrest's and Tempel's may have had their origin, likewise, in the collision of members of the group of asteroids.

ST. PAUL, Minnesota, Jan. 7, 1893.

ASTRONOMY IN 1893.

WM. W. PAYNE.

More than one month of the new year will have passed before these suggestions will be read by those for whom they are intended. In the January issue of this publication little was said about changes or plans for 1893, because they were not definitely arranged then; neither are they completed now so as to speak of them in detail satisfactorily. However something will be indicated in this brief article regarding the place this periodical may fill before we are done, after other suggestions are made concerning the outlook for Astronomy for the year 1893.

One noticeable feature of the present status of practical or observational astronomy is the multiplication of good and useful astronomical instruments. The increase in size, the various kinds and the expensive outlays for such equipments indicate something of the plane of activity of prevailing thought that concerns immediate plans for the benefit of astronomical science in general. The founding of Lick Observatory a few years ago, a similar unsuccessful attempt later by the University of the Pacific at Los Angeles, the planning of the 10-foot mirror in France, the 40-inch refractor in process of construction by Mr. Alvan Clark of Cambridgeport, Mass., at the present time for the Yerkes Observatory of the University of Chicago, besides other mammoth schemes in the interest of astronomy not yet made public, sufficiently show the drift of public thought in regard to the tools of the astronomer for modern research. This means very much for science when it is remembered that the large sums of money necessary for these grand enterprises come, in most cases from persons of wealth, not especially skilled in science, but who have intelligent and hearty interest in its true and rapid progress in almost every way that meets the approval of men having recognized ability in astronomy. A person can not be mistaken concerning the breadth of this philanthropic spirit, when he notices that there is a demand at Roberts' College, in Turkey, for a supply of astronomical instruments which will cost $10,000. The money has been given, and the instruments are now being made in this country for that college. A like request has already come from Anatolia College, at Marsovan, Turkey, for a similar outfit of instruments, and it must and will be met promptly. In this last case an Armenian scholar has been in special training for nearly three years, in a post-graduate course in mathematics and astronomy at the Goodsell Observatory of Carleton College, for the purpose of fitting himself thoroughly for instruction and practical work in these branches in Anatolia College.

This suggests also the fact that more attention is being given to the proper training of teachers and scholars in mathematics and astronomy during the last three years than previous to that time. Able astronomers and mathematicians are in demand in professional life, at fair or inviting salaries, and they have little time to give to the instruction of students in special lines. If this work is done as it should be, it must be done by colleges fitted for it, with courses, instructors, equipments and time for thorough work. A few years ago it would have been difficult to find such opportunities anywhere in the world, if we except a very few places. But it is different now. There are already a number of colleges in this country that are offering excellent opportunities for exactly the preparation that is needed for work of high character. All this contributes in more ways than one to the end of original study in some of the various branches of astronomy.

Then, the really important question is how is it possible to bring all these means of study, all these astronomers, professional and amateur, all these observatories and isolated instruments into useful and associated activity so as to bring out the most and the best results possible for the general advancement of astronomical knowledge. However desirable it may be to have many changes in the existing order of things, it is not possible to bring it all about in a single year. No one will suggest or endorse this. But it is true that something useful to astronomy can be done. In view of the true scientific spirit of the times it seems as if something ought to be done.

As a first step towards arousing a broader and a more lively interest in work going on by the professional astronomer, it may be suggested that the whole field ought to be better understood by the individual workers in the different parts of it. This might be done if astronomers were willing to make brief and regular reports to the astronomical journals of different countries, or even to one, if to report to more would be irksome. This publication has several times suggested this point, and, as often, offered to publish such accounts of their work regularly, as astronomers were willing to furnish. But only limited response came in consequence of it. The reason may be that most of the professional workers are not in the habit of this thing, and neglect it; or they are too busy and have no time to give to it. If either supposition is true, it is to be regretted. However, we are of the opinion that if a suitable leaflet or blank should be prepared and sent to astronomers generally, soliciting such items of news, facts and notes concerning individual work, discovery, theory or plan, that something useful would come of it. This will be undertaken soon, and suggestions concerning it from any source, will be thankfully received. We have no prizes to offer in this direction. It would doubtless greatly aid the enterprise if we had. That which is done in respect to prizes for useful comet work, as offered in a recent number of *The Astronomical Journal* is an excellent thing. It is producing good results in some quarters already. The *Journal* will doubtless, have all the comet matter it can take care of in the future, and cometary astronomy will be fostered generously. It is to be hoped that many other generous persons will recognize a like need in the proper study, classification and records of the minor planets. This theme has grown so large that it is a burden to the ordinary observer to keep track of it. A single illustration will show this. In attempting to account for the origin of the Holmes' comet after its orbit had been determined, the thought was suggested by two astronomers independently, that its sudden appearance may have been caused by the collision of two asteroids. As shown elsewhere in this issue a reasonable test of this hypothesis would be found in a somewhat critical examination of many of the orbits of the asteroid belt, with the aid of some important facts about them all. The present knowledge of the orbits, motions and places of the minor planets is not so complete or so well arranged and stated, as to make it an easy task to obtain the needed data for the study of this interesting question. This is saying nothing against that model work in this field which has been done by Professor Daniel Kirkwood. Indeed, it is such work as his with that of some others in Europe that has opened the door of possibility in this direction, and shown what may be done individually and from personal interest in a given theme. Now, if means and coöperation may be secured to put such needful work forward, und systematize it, knowledge of the theme itself and others related to it will certainly be improved. What is said of this particular field, may also, as well be said of many others. The general thought is systematic and associated work, with suitable endowment for it. There are competent scholars enough, instruments are not wanting, the desire, on the part of many, to do some useful work in astronomy was never greater. If, now, the year 1893 should bring about some needed changes in regard to these important suggestions, the advantages gained would richly repay all possible judicious outlay of money and energy to secure them.

THE STAR OF BETHLEHEM.*

LEWIS SWIFT.

I have read with great interest, as published in the *Astronomical Journal* of Nov. 26, Prof. Stockwell's "Supplement to Recent Contributions to Chronology and Eclipses." It shows much research and mathematical computation, and appears to add to our scanty knowledge of ancient chronology not only, but to settle many disputed points as well, but the concluding portion of the article relative to the star seen by the Wise Men in the east, though interesting and ingenious, is, in my opinion, untenable.

He proves from mathematical calculations that B. C. 6, there occurred on May 8 of that, year, a close conjunction of the planets Venus and Jupiter (yet 32′ asunder at their nearest approach), and, therefore, infers that this was the phenomenon which was seen of the Magi. He emphasizes the fact that the conjunction took place in the eastern morning sky which to his mind, harmonizes with the scriptural account, "For we have seen his star in the east." But this interpretation of the passage is strained and one it will not bear. Its meaning is simply this: that while they, themselves, were in the east they saw the star, not that the star was to the east of them. It is as if a person from Georgia who, while in this latitude, should witness an auroral display, and should assert that he had seen the same phenomenon in the south, not intending to convey the idea that the aurora was observed in the southern sky, but that he, the spectator, was stationed in the south. Or, again a man writing from, say, Oregon, a description of the geysers in the National Park might declare them the greatest wonder in the west, and yet he certainly would not be held to indicate that the National Park lay to the west of him.

Considering the star as of celestial origin, it is self evident that whether a conjunction of two planets, a bright comet, or the sudden appearance of a temporary star like that of 1572, as some contend, the body must have presented the same aspect at Jerusalem as in the east, which was not the case, or the troubled queries of Herod, who inquired diligently of the Wise Men what time the star appeared, would have remained unasked. Though all Jerusalem was troubled at the announcement, it is evident that no unusual celestial phenomenon was witnessed.

Again, the Magi were, doubtless, aged men who must many

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* Communicated by the author.

times have beheld a conjunction of bright planets as well as the apparition of a brilliant comet, and so common an event as either would hardly have induced them to undertake so long a journey with the dubious prospect, from so ordinary an omen, of finding the promised Messiah.

According to Professor Stockwell the two planets were at their nearest approach over a half a degree apart, and of course, appeared as two separate stars, which fact is at variance with their statement, for they saw but one.

That this conjunction was supernatural, or, that the birth of the Savior was deferred until this celestial phenomenon occurred, are both assumptions too unreasonable to be accepted.

Taking into consideration that the Bible makes mention of only three kinds of heavenly bodies, viz.: Sun, Moon and stars, and that every unusual light, celestial or mundane, was called a star, I feel justified in emphatically asserting that what the Wise Men saw was not a star at all but a supernatural light which, quite likely, appeared in their own dwellings or, at least, at their dwelling places, and was not again visible until their arrival near Bethlehem when it re-appeared and "went before them till it came and stood over where the young child was."

As Venus was approaching superior conjunction with the Sun, it is plain that another with Jupiter could not occur, and, hence, the question arises, if the "star" they saw while in the east was a conjunction of Venus and Jupiter, what one was observed on nearing Bethlehem? The Bible declares it to have been the same star, but as several days or weeks were spent in journeying to the place of the Nativity, and as Venus was moving rapidly away from and was, probably, by the time of their arrival at Bethlehem, from ten to twenty degrees east of Jupiter, it could not possibly have been the same conjunction.

A star proper cannot by any possibility go before and guide a person to any particular house, any more than it can indicate a certain branch of a solitary tree.

Taking into consideration all the circumstances connected with this much discussed question, I am strongly of the opinion that, though of Divine origin, the phenomenon seen of the Wise Men was wholly terrestial and local. The theory of Professor Stockwell robs the extraordinary event of all supernaturalism, not only, but antedates the generally received time of the Saviour's birth by two years, or more than a year before the angel's annunciation.

WARNER OBSERVATORY,
Rochester, N. Y., Jan. 3, 1893.

THE ABSORPTION OF LIGHT IN SPACE.*

W. H. S. MONCK.

The problem whether any appreciable quantity of light is absorbed in traversing space has often been mooted without receiving satisfactory answer. It seems clear indeed either that there is such an absorption, or that there is a gradual thinning out of the stars—at least of luminous stars—as we proceed outwards from the Sun., For otherwise, the entire sky would glow with at least the brilliancy of the full Moon. And this conclusion is supported by other reasons. Taking the light-ratio of 2.512 to 1 for one magnitude, the stars of any given magnitude would be nearly four times as numerous as those of the magnitude next below it, assuming that the average distribution was uniform and that no light was lost in transmission. But so far as photometric measurements have extended, the proportion is always less than this. Three to one would be nearer the mark than four to one and would probably be too high also. A loss of light in transmission affords perhaps the most satisfactory explanation of this difference.

It recently occurred to me that a comparison of the proper motions of the stars of different magnitudes might lead to a solution of the problem. Assuming the average velocity of the stars to be the same at all distances from us, their average proper motions would vary inversely as the distance. Supposing then, that a difference of one magnitude corresponds to a ratio oj 2.512 to 1 in the amount of light, it corresponds to a ratio of 1.585 to 1 (the square root of the foregoing) in the average distances, or pretty nearly to a ratio of 1.25 to 1 for a half-magnitude. The average proper motions should diminish in this ratio for each half-magnitude assuming that there is no loss of light. But on the assumption of a loss of light in traversing space, the light of a distant star will diminish more rapidly than in the ratio of the inverse square of the distance. The distance-ratio, corresponding to a difference of half a magnitude, will, therefore, be less than 1.25 to 1, and the average proper motion will, of course, be diminished in less than that ratio. It seemed, therefore, that there was a prospect of deciding the question by a comparison of the proper motions of a number of stars whose photometric magnitudes had been determined, and ascertaining the rate at which these proper motions diminished for each half-magnitude.

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* Communicated by the author.

I had already noticed that there were great differences in the proper motions of stars of the same magnitude with different kinds of spectra, and I therefore resolved to take the results separately for the Sirian stars (A and B of the *Draper Catalogue*, the Arcturians (H, I and K of the same Catalogue) and the Capellans (E and F). I took up the Pulkova Catalogue of Proper Motions and ascertained, in as many cases as possible, the spectrum of the star together with its photometric magnitude (from the *Harvard Photometry*). The number of stars between 4.0 and 6.5 seemed large enough to warrant taking the results separately for each half-magnitude; though I suspect that those for magnitudes 6.0 to 6.5 are too high, many stars having been inserted in this part of the Pulkova Catalogue on account of their large proper motions where their compeers with smaller proper motions are omitted. I examined the proper motions in declination only, as those in R. A., which would be more troublesome to tabulate, probably followed the same law. To avoid the effect of a few stars with abnormally large proper motion, I took as the mean the point where the number of stars with greater and less proper motion was equal. Lastly, as Auwers' Catalogue contains a larger number of bright stars than the Pulkova Catalogue, I carried the table back to magnitude 3.0 by consulting it—omitting, however, the division 3.0 to 3.5 in the case of the Capellan stars because I had only 5 stars of this class to deal with. The following are my results:

SIRIAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	29	0.0345	5.0 to 5.5	283	0.018
3.5 to 4.0	46	0.0255	5.5 to 6.0	236	0.018
4.0 to 4.5	57	0.021	6.0 to 6.5	72	0.021
4.5 to 5.0	149	0.019			

ARCTURIAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	24	0.036	5.0 to 5.5	158	0.0255
3.5 to 4.0	46	0.0545	5.5 to 6.0	150	0.025
4.0 to 4.5	46	0.031	6.0 to 6.5	45	0.025
4.5 to 5.0	91	0.026			

CAPELLAN STARS.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.5 to 4.0	13	0.154	5.0 to 5.5	75	0.067
4.0 to 4.5	14	0.109	5.5 to 6.0	82	0.047
4.5 to 5.0	41	0.044	6.0 to 6.5	32	0.062

These results are hardly satisfactory. With the fainter Sirian and Arcturian stars indeed, the ratio of decrease is very decidedly less than 1.25 to 1 for each half magnitude, but the difference seems too great to be accounted for by the loss of light in space. The average motion in these cases is very small and I suspect that errors of observation and computation contribute largely to the result. Where the quantities of motion are larger, as in the Capellan stars and the brighter Sirians and Arcturians, there is considerable fluctuation in the results, but I do not think it can be said that taking them all round, the average decline is less than 1.25 to 1 for each half magnitude. The data which I have examined would thus appear insufficient to decide the question. It may be worth while, however, to give another table setting out the results obtained for all the stars including some whose spectra are not given or are not reducible to any of the foregoing heads. In this table those between magnitudes 3 and 4 are taken from Auwers' Catalogue and between 4 and 6.5 from the Pulkova Catalogue.

AVERAGE.

Magnitude	Stars	Av. Motion in N. P. D. ″	Magnitude	Stars	Av. Motion in N. P. D. ″
3.0 to 3.5	65	0.032	5.0 to 5.5	548	0.022
3.5 to 4.0	124	0.044	5.5 to 6.0	503	0.022
4.0 to 4.5	121	0.025	6.0 to 6.5	173	0.021
4.5 to 5.0	305	0.023			

I do not think the absorption of light in space can be great enough to account for this extremely slow rate of diminution. When the other causes are discovered, we shall be better able to judge of their sufficiency without calling in the aid of this absorption. The problem may perhaps be approached in a different way, viz., by ascertaining the number of stars with different amounts of proper motion and finding how the number of stars increases as the motion diminishes. But here too, I fear our Catalogues are not, at present, complete and accurate enough to afford decisive results.

PHOTOGRAPHING MINOR PLANETS.[*]

DR. MAX WOLF.

In December 1886, Dr. Isaac Roberts first succeeding in photographing with his telescope the minor planet Sappho, estimated to be of the 11th magnitude. The planet described a short trail

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[*] From the *Journal of the British Astronomical Association*, Dec. 17, 1892.

on the plate amongst the stars near the place of the ephemeris; and from the plate the correction of the ephemeris was immediately obtained.

The difficulty in detecting a minor planet, amongst the enormous number of faint stars, by eye-observation is very great, because it is only by its movement that the planet can be discerned. The observer must, therefore, make a diagram of the region in which he supposes the planet to be. After a time, on comparing the diagram star by star with the sky, he finds that one star—the planet he sought for—has moved, always supposing, that is to say, that he has examined its right place, and not, by mistake, a neighboring but inaccurate position. Photography holds out two great advantages over that method; it gives a larger field, while the planet marks its trail and therefore immediately distinguishes itself from the surrounding stars.

I commenced photographing minor planets in August 1890, using both a telescope lens of 16.2cm. aperture and 262cm. focal length, and an aplanatic lens of 6cm. aperture and 44cm. focal length. I was seeking for several lost asteroids at the time during several nights, and used ten plates with long exposures. I had no success because I could not employ suitable lenses, the focal length of the first employed being too long, and the aperture of the second too small. To photograph minor planets both a large field and a marked brightness of image is required. For photographing nebulæ the brightness* has as factor the quantity $\frac{D}{F^2}$, where D is the diameter of the object-glass and F the focal length of the lens employed. But it is quite a different thing with asteroids, of which the area is a "point." The brightness of the image on the plate would be the same as from a fixed star of equal intensity. It would have as factor the quantity D^2, if we neglect for simplicity's sake the small influence of the focal length. But the asteroids are moving and are drawing a trail amongst the stars on the plate. This trail becomes longer when using a lens of longer focus, the intensity of a planetary trail drawn by a longer focus lens is diminished. It therefore results that the brightness has as factor the quantity $\frac{D}{F^2}$.

To photograph asteroids, therefore, we need a lens with an aperture as great as possible, with a focal length as short as possible, and giving a large field; as for instance, a large portrait lens.

From this point of view I recommenced the photography of

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* *Journal*, British Astronomical Association, 1891, p. 252.

minor planets in November 1891, using my 5¼-inch Kranz aplanatic lens. After some experiments in focussing the plate, I succeeded in getting on my plate, on the evening of December 22, the first *new* minor planet discovered by means of photography. This is No. 323, "Brucia." On the same plate I found the lost planet 275, "Sapientia," both of the 12th magnitude.

For the identification of this planet, and also for invaluable assistance in calculation, I am indebted to Herr Berberich, of Berlin, the well-known "surveyor" of the orbits of asteroids.

Since then I have photographed a great number of old and new minor planets. From 1891, November 28, till 1892, April 25, I got 125 different positions of 58 different minor planets; 17 of which were new discoveries.

For the most part the positions were roughly taken from the Argelander charts, but a great number were measured. This measurement is quite simple. A microscope with a long focus object lens and supplied with a filar micrometer in the eye-piece is alone required. The distance of the middle of the planetary trail from several known stars on the plate is measured. The distances give, by a simple trigonometric example, the differences in R. A. and in N. P. D. from one of the known stars. The accuracy gained by this simple arrangement is within a fraction of one second of arc; the measures are therefore equivalent to eye observations.

Since May 1892, besides many known planets, several lost, and several new planets have been discovered by my photographic lenses, and it has been found necessary since August, to introduce a new method of reckoning the newly discovered asteroids.

I hope the fact will be of interest for your members that the new planet "1892 C," was discovered by my friend, Mr. A. Staus, who is a member of your Association.

The success already obtained proves that it is easy to find all the hitherto lost minor planets, and to arrange for a simple and sure watch over all the known asteroids, working with lenses of large field and great light-grasping power, and by means of the self-registering action of the planetary trails on the photographic plates.

The work is very straining and fatiguing, because I have to expose each plate for two hours, controlling without intermission the driving clock by the guiding telescope. But this is only caused by the want of means to procure a larger lens and a better clock, and unfortunately there is little hope of obtaining them in Germany.

HEIDELBERG OBSERVATORY, 1892, September.

THE DOUBLE STAR Σ 2145.*

H. C. WILSON.

On the night of June 8, 1892, while taking a measure of the double star Σ 2145, I noticed that the larger component was itself a very close double, and estimated the distance at 0″.3. My measures gave position angle 44°.7; distance 0″.52. I have reason to suspect, however, that for several nights during the summer a little knot on one of the micrometer threads caused them to catch a little as they passed so that I could measure nothing less than 0″.5. The night was a very fine one, bearing a power of 1,000 readily, and the stars were clearly separated. Several other close doubles were measured on the same night, among them OΣ 309, which is described in my notes having "beautiful images; no rings; distinctly separated." The power used in all the measurements was about 500. On subsequent nights, when the seeing was fair the close components of Σ 2145 could not be distinctly separated but on every occasion the elongation was easily noticed.

I speak of this star because it is likely to prove an interesting binary and because its discovery indicates something of the excellent defining power of the 16-inch refractor which was made for Goodsell Observatory by Messrs. Hastings and Brashear. Both Professor Hough and Mr. Burnham on different occasions, not, however, under best atmospheric conditions, tried the star with the 18-inch refractor of Dearborn Observatory and failed to detect duplicity or elongation.

At Mr. Burnham's request Mr. Barnard looked up the star with the 36-inch refractor at Lick Observatory and pronounced it a fine double. He has recently sent me his measurements, which I give below.

The Struve pair has been measured by several observers since 1829 and its distance has increased 3″, evidently from proper motion. It seems from this that the new pair must be a binary and that its distance has for the last 60 years been very small, otherwise some of the observers must have detected it. The following are all the measures which I have at hand. Some of the earlier measures were kindly furnished me by Mr. Burnham:

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* Communicated by the author.

MEASURES OF THE Σ PAIR.

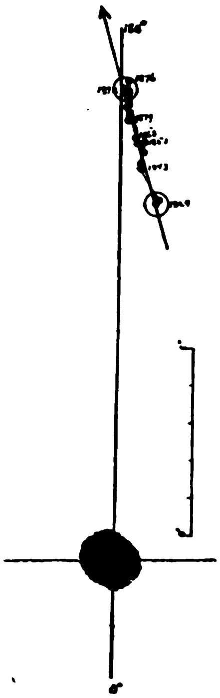
Epoch.	Pos. Angle. °	Distance.	No. of Nights.	Observer.
1829.68	174.4	9.72	1	Struve.
32.30	174.1	9.87	1	"
43.65	177.0	10.61	3	Mädler
45.17	177.2	10.74	4	"
51.69	176.9	11.29	..	"
52.33	178.0	11.26	..	"
54.78	176.8	11.12	..	"
58.72	178.8	......	..	"
63.41	178.2	11.32	..	Dembowski
76.47	178.8	12.93	1	Wilson and Seabroke
77.45	179.1	12.64	1	Fletcher
79.24	178.6	12.25	3	Schiaparelli
79.37	177.9	11.89	2	Howe (Cincinnati 5)
92.55	179.5	12.74	3	Wilson

MEASURES OF THE NEW PAIR BY H. C. WILSON.

Epoch.	Pos. Angle. °	Distance.	Magnitude.	
1892.437	44.7	0.52	8.0	8.5
.593	39.1	0.3 ± est.	8.5	9.0
.596	43.2	0.3 ± est.	8.0	9.0
.609	48.9	0.67	8.5	9.5
.623	45.4	0.53	8.5	10.0
.648	51.1	0.42	8.5	10.0
1892.584	45.4	0.46	8.3	9.3

MEASURES BY MR. BARNARD.

1892.809	49.9	0.4 ± est.	nearly equal.
.814	50.2	0.40	
.847	49.0	0.43	
1892.823	49.7	0.41	



Σ 2145.

R. A. 17h 12m; Decl. 26° 43′.

WORK FOR LARGE TELESCOPES.*

EDWARD C. PICKERING.

A wide popular interest is now felt in telescopes of the largest size. The general public has no doubt an inordinate idea of what they should show. Some persons, however, considering the great cost and supposed limited field of work of a large telescope, maintain that results of greater value might be reached by a different expenditure of money. Undoubtedly, in the United States, the capital invested in large telescopes is out of all proportion to the income available for keeping them at work, and perhaps on this account the results attained are less than might be expected. As difficulty is often found in providing suitable work for a large telescope, it may be worth while to enumerate some of the researches in which such an instrument might secure results which could not be obtained with a smaller instrument. As it is not easy to decide whether more useful results could de obtained visually or photographically, it would be a great mistake to make the instrument of such a form that it could not be used in both ways. This is readily done by making the front lens reversible, with surfaces of unequal curvature. The additional expense is slight, and the objection that the photographic field is diminished owing to the necessary separation of the lenses, is not important when the focal length is very great, since the available field is then larger than can be conveniently covered by a single photographic plate. The only large lens as yet used in this way has an aperture of thirteen inches, and is now at the Harvard station in Peru. The photographic results in California, and the visual results in Peru indicate that when employed in either way its definition is unsurpassed. The focal length of the instrument here proposed should be as great as possible. The Bruce photographic telescope will have such advantages over other instruments when a relatively short focal length is desired that competition with it in this respect would generally be undesirable. The focal length is likely to be limited by the mechanical difficulties and the expense of constructing a suitable dome. The optical difficulties diminish with the increase of focal length.

A telescope of the largest size, constructed so that it could be used either visually or photographically, and mounted in a location where the atmospheric conditions were favorable could be usefully employed on either of the twenty researches enumerated

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* Communicated by the author.

below. A portion of them have already been undertaken with the 15 and 13-inch telescopes at the Harvard stations at Cambridge and Arequipa. They should be extended to stars beyond the reach of the Harvard instruments.

1. Micrometric measures of close double stars. The great focal length should render the errors extremely small.
2. Micrometric measures of faint satellites.
3. Positions of comets only when beyond the reach of smaller instruments.
4. Diameter of planets, satellites and bright asteroids.
5. Approach and motion of all known gaseous nebulæ by visual observations of their spectra, as has been done in certain cases at the Lick Observatory.
6. Photometric measures of the light of faint stars selected as standards, including faint comparison stars for variables, stars selected from clusters, standards proposed by the Committee of the American Association (Proc. XXXIV, 1). The measures may be made with the aid of a wedge, a Zöllner photometer or an auxiliary telescope (Harvard Annals, XI, Part II, XIII, Part II).
7. Relative brightness of components of double stars (Harvard Annals, XI, Part I.
8. Photometric measures of Jupiter's satellites, while undergoing eclipse.
9. Measures of the intensity of the various portions of the brightest nebulæ, and the central portions of the fainter nebulæ. At Cambridge this is done by comparing with the image of a known star in an auxiliary telescope thrown out of focus by a measured amount. If the nebula has a stellar nucleus throw it also out of focus by a known amount. This gives the mean brightness of the vicinity of the nucleus. Apply the same method to comets. Measure clusters in the same way, throwing them out of focus until the separate stars are indistinguishable. This seems to indicate the density of the cluster, or ratio of the mean diameters of the stars to their distances apart.
10. Observations by Argelander's method of variables when too faint to be observed elsewhere.
11. Examination of all stars brighter than a given magnitude for faint and close companions.
12. Study of clusters in connection with photographs, to determine the number of stars in portions not resolved in the phophotographs (see No. 16).
13. Study of the surfaces of the Moon, planets and satellites with very high powers. This can be done usefully only if the location is such that the air is extremely steady.

14. Search for faint planetary nebulæ, bright line stars (near central line of the Milky Way) and stars of the fourth type. Use a direct-vision prism or a prism of small angle near the focus with an eye-piece of very low power.

15. Study of the spectra of known nebulæ when large with a slit spectroscope, when small with the apparatus described in No. 14. Of the nine or ten thousand known nebulæ and clusters the spectra of about a hundred only are known to be gaseous and of a few hundred more to be continuous. The composition of all the rest is unknown. The spectra of some clusters may be peculiar.

16. Photograph doubles and all clusters coarse enough to be resolved, and measure the relative positions and brightness of the components.

17. Photograph Jupiter's satellites while undergoing eclipse. Move the plate in declination every 5 or 10 seconds thus obtaining a series of images.

18. Photograph the Moon and planets enlarging the image in the telescope by means of an eye-piece especially constructed for the purpose.

19. Measure the approach and recession of the stars from photographs of their spectra as has been done at the Potsdam Observatory.

20. Photograph the spectra of the coarse clusters and doubles with the apparatus described in No. 14. Short spectra with poor definition are thus obtained, but very faint stars can be photographed and the separation due to the great focal length will show to which type they belong, even if they are very closely crowded together.

The last five researches will be excluded if the telescope cannot be used photographically. In this case, something might still be done by using plates stained with erythosin. Great steadiness of the air, such as seldom occurs at existing Observatories, is requisite for Nos. 1, 4, 11, 12, 13 and 18. For Nos. 3, 6, 9, 10, 14 and 15, the sky must be dark and no electric lights near.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

THE ASTRO-PHOTOGRAPHIC CHART.*

HAROLD JACOBY.

The general purpose of this important international enterprise is well known; but now that the making of the negatives has actually begun, it may be of interest to give a brief sketch of the present condition of the work, as shown by the action taken at the more recent committee meetings. Some of the resolutions previously adopted have since been repealed or amended; others, though not formally repealed, have failed to be carried into execution. It will thus be seen that there is now a tendency to allow a certain flexibility in the interpretation of the resolutions. Whenever possible, individual opinion is to direct individual effort, and absolute uniformity in the work of different observatories is to be insisted upon in matters of fundamental importance only. There does not seem to be any probability that the enterprise will fail, either on account of differences of opinion, or from an attempt to attain too high a degree of accuracy or uniformity.

Selecting from among the many details recently published concerning the work, it is interesting to note the way in which the plates are to be distributed upon the sky. It will be remembered that the photographic refractors are to have an aperture of $0^{m}.33$, and a focal length of about $3^{m}.43$. Thus a minute of arc upon the sky will correspond to about 1^{mm} on the plates. The latter are to be 160^{mm} square, but the "effective field" is to be taken as only two degrees square. Now, neighboring plates are to overlap in declination by at least half their diameter, so that a star situated at the center of one plate will also be found near one corner of the effective field of the next plate. In order to accomplish this in the simplest way, the plates are to be exposed so that their centers will lie upon successive parallels of declination one degree apart. The whole sky will thus be covered by successive bands of plates. Now the center of the first plate for bands of even declination will correspond to 0^{h} 0^{m} of right ascension. For the bands of odd declination, the first plate will be centered upon a point whose right ascension is approximately the mean of the right ascensions belonging to the first and second plates of the neighboring band. This arrangement will be easily understood from the accompanying table. Near the equator it will be sufficient to have the other plates of each band

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* Communicated by the author.

follow at intervals of 8^m of right ascension. But as the declination increases, the right ascensions of contiguous plates will differ by more than 8^m, until at last, the polar band will contain one plate only. The arrangement finally decided upon is exhibited in the following table:

TABLE OF ARRANGEMENT OF PLATES.

Declination of Band.	R. A. of First Plate of Band				Interval R. A. Consecutive Centres.	No of Plates in 1 Band.	Total No. of Plates.
	Even Decl.		Odd Decl.				
° °	h	m	h	m	m		
0 to 27	0	0	0	4	8	180	4950
28 to 36	0	0	0	4	9	160	1440
37 to 48	0	0	0	5	10	144	1728
49 to 59	0	0	0	6	12	120	1320
60 to 63	0	0	0	8	16	90	360
64 to 66	0	0	0	9	18	80	240
67 to 70	0	0	0	10	20	72	288
71 to 74	0	0	0	12	24	60	240
75 to 78	0	0	0	15	30	48	192
79 to 82	0	0	0	20	40	36	144
83 to 85	0	0	0	30	60	24	72
86 to 87	0	0	0	45	90	16	32
88	0	0			120	12	12
89			1	30	180	8	8
90						1	1
Total No. of Plates for one Hemisphere							11027

The numbers in the fifth column of this table are obtained by dividing 1440 (the number of minutes in 24^h) by the interval of successive centres as given in column 4. The last column is obtained by multiplying the number of plates in one band (as given in the fifth column) by the number of bands (as indicated in the first column). But the plates whose centres are at 0° declination are credited half to each hemisphere. Thus, for instance, from 37° to 48° there are 12 bands of 144 plates each, or 1728 plates in all. Now suppose we wish to know what plates will contain a star in R. A. $0^h\ 47^m$, Decl. 39° 40′. The above table shows that it will be on the 6th plate of the 40° band and the 5th plate of the 39° band. For in accordance with the explanation already given, the bands of odd declination have the first plate at $0^h\ 5^m$ right ascension for declinations between 37° and 48°.

Of course, in order to make certain that the plate is really exposed to the proper point on the sky, it is necessary for the astronomer to bisect a certain known guide-star, with the micrometer of the guide-telescope attached to the photographic equatorial. The selection of these guide-stars from the existing star catalogues has caused considerable trouble. It was at first intended that they should not be further than 22′ from the centre of the plate, and the lists have been drawn up accordingly. But in order to accomplish this, it has been found necessary to admit many stars of less than the 9th magnitude. It has, therefore, been finally decided that each astronomer may select a fresh guide-star not more than 40′ from the center, whenever the star set down in the official list shall, in his judgment, appear too faint for easy observation in a bright field.

It is perhaps unnecessary to refer to the much discussed question of the réseau. This consists of a plate of silvered glass, upon which two series of parallel lines are ruled so as to divide the whole surface into small squares 5^{mm} by 5^{mm}. Before the plates are exposed to the sky, they are covered with the réseau plate, and the whole exposed for a short time to parallel light. In this way a latent image of the réseau is impressed upon the plate, and will appear during development. It is plain that by afterwards measuring the star's positions with respect to the nearest réseau lines, we can secure results that are independent of any possible deformation of the film during development. It has been decided that the réseau shall be applied to all plates, but the method of application is left to the individual judgment of each astronomer. With regard to the focussing of the plates, no definite decision has been reached: but it is probable that the focal plane will be selected so as to give the best images for a point about 40′ from the centre of the plate. The orientation of the plates is to be such that one set of lines of the réseau will be parallel to the equator. For plates whose declination is greater than 65°, the orientation is to be referred to the equator of 1900; other plates will be oriented according to the apparent equator of the day.

The question of duration of exposure, in relation to the photographic magnitudes of the stars has given rise to much discussion. It will be remembered that the series of plates destined for the formation of the chart are to contain all stars to the 14th magnitude, while the series of shorter exposure, from whose accurate measurement a catalogue is to be constructed, must show all stars to the 11th magnitude. It seems likely that the discussion of this question will end in the simple practical expedient of making a trial negative each night of some type-region of the sky. Now, if the magnitudes of the stars in the type-region have been previously adopted as known, it will be easy to find out the exposure necessary on any particular night to insure the presence on the negatives of all stars of the desired magnitude. This process will probably lead to a considerable degree of uniformity in the results from the several observatories. And after all, the astro-photographic project does not aim too high. It is intended to secure what astronomers have always sought for;—observational results of the highest *attainable* accuracy. In order to prevent the occurrence of "false stars," such as would be caused by specks in the film, it may be found necessary to have double or triple images on the chart plates. This question has not been definitely decided, but it seems probable that the plates of even declination will have single images, while the series of odd declination, to be made later, will have triple images.

With regard to the measurement of the catalogue plates, each observatory is to begin as soon as convenient. The measures need not necessarily be made at the observatory itself, but the plates may be sent for measurement to some other observatory, or to some "bureau of measurement." The uncorrected results of these measures are to be published by the several observatories. -The final reduction will be undertaken by the permanent committee, as soon as the question of standard stars can be settled. It is obvious that in the final rigorous computations the orientation and scale value must always be obtained from measures of the images of several standard stars impressed on the plate. For the whole heavens, it would thus be necessary to know accurately the positions of some sixty or seventy thousand stars. Now the existing star catalogues are not sufficient to furnish these positions. It seemed, therefore, as though the final reduction of the catalogue plates would have to be deferred until the requisite number of stars could be determined in the meridian. Fortunately, a plan has been proposed by M. Loewy which will, in all probability, do away with this formidable difficulty. This plan consists in taking advantage of the circumstance that the plates overlap in declination by at least half their diameters. Indeed, it is obvious that by means of the stars common to two overlapping plates, we can, as it were, connect the two together, just as though they were merely parts of a single plate. For this purpose it is, of course, not necessary that the stars common to the two plates should be previously well determined. Now as the arrangement of the successive bands is such that every plate has four others overlapping, it is clear that the above process will be equivalent to giving us a space of four plates; or sixteen, instead of four, square degrees, wherein to look for standard stars. In so large a space, the existing catalogues will almost always furnish a sufficient number. It is difficult to foresee any reason why this plan of M. Loewy's should fail: the results of a practical trial will doubtless soon be published, and will, it is hoped, set this important question definitely at rest.

In conclusion, it may be of interest to set down the names of the several Observatories taking part in the work, together with the zones assigned to each for observation.

TABLE SHOWING DISTRIBUTION OF WORK.

Observatory	Latitude. ° ′	Decl. of Zone. ° °	Zenith Distance. ° ′ ° ′	No. of Plates.
Greenwich	+ 51 29	+ 90 to + 65	− 13 31 to − 38 31	1149
Rome	+ 41 54	+ 64 to + 55	− 13 6 to − 22 6	1040
Catania	+ 37 30	+ 54 to + 47	− 9 30 to − 16 30	1008
Helsingfors	+ 60 9	+ 46 to + 40	+ 14 9 to + 20 9	1008
Potsdam	+ 52 23	+ 39 to + 32	+ 13 23 to + 20 23	1232
Oxford	+ 51 46	+ 31 to + 25	+ 20 46 to + 20 46	1180
Paris	+ 48 50	+ 24 to + 18	+ 24 50 to + 30 50	1260
Bordeaux	+ 44 50	+ 17 to + 11	+ 27 50 to + 33 50	1260
Toulouse	+ 43 37	+ 10 to + 5	+ 33 37 to + 38 37	1080
Algiers	+ 36 48	+ 4 to − 2	+ 32 48 to + 38 48	1260
San Fernando	+ 36 28	− 3 to − 9	+ 39 28 to + 45 28	1260
Tacubaya	+ 19 24	− 10 to − 16	+ 29 24 to + 35 24	1260
Santiago	− 33 27	− 17 to − 23	− 10 27 to − 16 27	1260
La Plata	− 34 35	− 24 to − 31	− 3 55 to − 10 55	1360
Rio Janeiro	− 22 54	− 32 to − 40	+ 9 6 to + 17 6	1376
Capetown	− 33 56	− 41 to − 51	+ 7 4 to + 17 4	1512
Sidney	− 33 52	− 52 to − 64	+ 18 8 to + 30 8	1400
Melbourne	− 37 50	− 65 to − 90	+ 27 10 to + 52 10	1149
Total number of plates				22054

THE COMETS OF 1892.*

H. C. WILSON.

Seven comets were discovered during 1892, all remaining visible until nearly the close of the year. Five of them are still visible with large telescopes. Comet 1890 II was rediscovered at Nice, 1892, Jan. 6, but no further observations have been reported. Wolf's periodic comet, found by Barnard May 3, 1891, and the Temple-Swift periodic comet, found by Barnard Sept. 27, 1891, were followed into the first months of 1892. Three periodic comets were due this year: Brooks 1886 IV, Tempel$_1$, and Winnecke. The first two were not found.

Comet *a* 1892.—Was discovered by Lewis Swift at Rochester,

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* Communicated by the author.

N. Y., on the morning of March 7. It was very bright and easily visible to the naked eye. At the time of its perihelion passage the tail of the comet was visible for 12° or 15° from the nucleus. Some beautiful photographs taken by Mr. Barnard at this time reveal interesting features in the structure of the comet which were not visible to the eye. Some of these photographs have been reproduced in *Knowledge*, Dec. 1892. The spectrum of this comet was observed by Campbell at Lick Observatory and found to be of the usual type, continuous for the nucleus and banded for the coma and tail. These observations were published in ASTRONOMY AND ASTRO-PHYSICS, Oct. 1892. The comet is still visible in large telescopes. With the 16-inch refractor of Goodsell Observatory on Jan. 12 it was faint, small and round, with a strong condensation in the center. It doubtless may be followed for another month yet. The orbit is very nearly a parabola. The elements calculated by Miss F. Gertrude Wentworth (*Astr. Jour.*, No. 273) represent the path of the comet quite well up to the present time.

COMET *b* 1892.—Winnecke's periodic comet was found with the 27-inch refractor at Vienna, March 18, within 4^s in R. A. and 10′ in Decl. of the place predicted by Dr. E. von Hærdtl (*Astr. Nach.*, No. 3062). In June and July it was quite a bright telescopic object. By the last of October it was again so faint as to be visible only in large telescopes.

COMET *c* 1892.—Discovered by W. F. Denning, at Bristol, Eng., March 18. It has all the time been a very faint comet but at last reports was still visible with a 10-inch reflector. The orbit is probably a parabola.

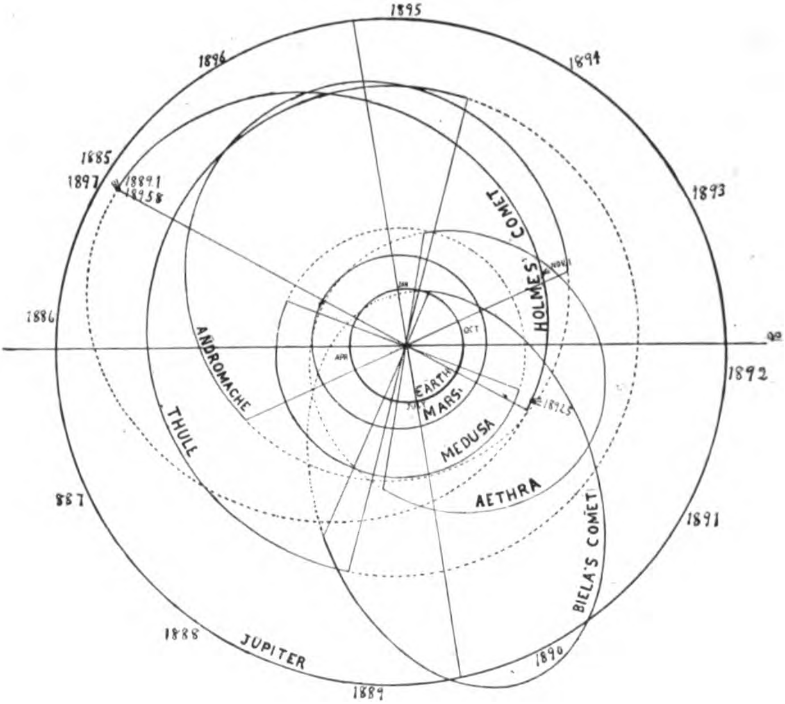
COMET *d* 1892.—Discovered by W. R. Brooks at Geneva, N. Y., Aug. 28. It was a bright telescopic comet with short tail. It increased quite rapidly in brightness reaching a maximum in December when the tail was visible to the naked eye, the length being about 5°. This comet is still visible but is too far south for observation in this latitude. The orbit is probably parabolic.

COMET *e* 1892.—Discovered on a photograph by Barnard Oct. 12. It is the first comet discovered by photography, and it is remarkable that a comet so faint visually should have been thus discovered. The comet very quickly faded away becoming invisible in the largest telescopes in a few weeks. The orbit is probably elliptic. Professor Krueger has obtained a period of 6.3 years. M. Schulhof has also computed elliptic elements, with a period of about 6 years, but the observations are too few to give any very certain results. M. Schulhof also calls attention to the similarity of these elements to those of Wolf's periodic comet. He suggests that the two have the same origin, are, in fact, parts of the same comet which separated at some time previous to 1885. In that year they were in the vicinity of Jupiter together and suffered violent perturbations by the planet. A relatively small difference in their epochs of passing peri-jove would be sufficient to produce the considerable difference in their inclinations and excentricities.

COMET *f* 1892.—Discovered by Edwin Holmes, in England, Nov. 6. So much has been said recently about this comet that it seems unnecessary to say more now; yet, for the sake of completeness of this article, a brief recapitulation ought to be given. The comet was so bright when discovered that it could be seen with the naked eye, and as it was in a region frequently examined by amateurs, only a few degrees from the great nebula of Andromeda, it seems remarkable that it was not discovered earlier, when theoretically it should have been brighter. Mr. Holmes says that he examined that region on Oct. 25 and observed nothing special.

Mr. Berberich, of Berlin, noticed that the comet was very near the Bielid meteor radiant and announced that possibly this might be Biela's comet, which has been lost sight of since 1852. As soon, however, as sufficient observations were obtained to permit the computation of an orbit, it was found that this comet was much farther away than Biela's and was receding from instead of approaching the Earth. The orbit is found to be a short ellipse, the period being about 6.9 years. The orbit is less excentric than that of any other known comet, and approaches more nearly to those of the asteroids. According to the elements of Professor Boss (*Astr. Jour.* No. 283), which represent the observations up to the present time very well, the aphelion distance is 5.12, less than that of Jupiter, and the perihelion 2.14, greater than the aphelion of Mars.

In the accompanying cut are given for comparison the orbits of Holmes' and Biela's comets and those of some of the asteroids and the planets, Earth, Mars and Jupiter. Thule (279) has the largest of the known asteroid orbits, Medusa (149) the smallest, Aethra (132) the most excentric. Aethra has the smallest perihelion distance and Andromache (175) the greatest aphelion distance. In drawing the diagram the inclinations of the orbits were neglected, so that they are shown in their true proportions though not in their true relation. The dotted portions lie below the ecliptic. If all the 350 and more asteroid orbits were to be platted in the same way, the space between Thule and Medusa would be so filled with intersecting ellipses that very little paper would be visible through the ink. A glance at the diagram shows that the orbit of Holmes' comet lies for the most part within the asteroid zone, but that it also approaches at aphelion so near to the orbit of Jupiter that it may be subject at times to violent perturbations. Running back with the period 6.91 years we find no close approach of the comet to Jupiter until the year 1861. The question then arises, why the comet has not been seen at some of the returns since that time. Its position would have been more favorable at each of those apparitions than at the present one.



Orbits of Holmes' and Biela's Comets and Some of the Minor Planets.

The unusual behavior of the comet in its rapid decrease of brightness and expansion of volume while receding from the Sun has also given rise to question as to the nature of its constitution. Its spectrum, too, distinguishes it from other comets, indicating that it shines principally by reflected sunlight. The spectrum, according to Mr. Campbell of the Lick Observatory, is continuous with perhaps traces of the usual cometary bands in the green and yellow (A. AND A. Jan. 1893). In view of these peculiarities Mr. Corrigan (A. AND A. Jan., 1893) proposes the theory that Holmes' comet had its origin in a collision of two asteroids a short time previous to Nov. 6, 1892. On another page in this number of ASTRONOMY AND ASTRO-PHYSICS he shows that none of the known asteroids can be components of the comet.

While this article was in preparation a change occurred in the comet which throws Mr. Corrigan's theory in doubt. For a month back the comet has been so exceedingly faint that it has been very difficult to determine its position micrometrically, even with large telescopes. On the night of Jan. 12 this was still true. On Jan. 16, however, the writer was astonished to find the nucleus and coma almost as bright as in November. The coma was less than 1′ in diameter but very dense, and the nucleus was as bright as an eighth magnitude star. Evidently some new commotion has taken place in the nucleus which it would perhaps be stretching the limits of probability to explain as the result of a new collision of asteroids. The same phenomenon was observed

Elements of the Comets of 1892.

	Synonym.	Discoverer.	Date of Discovery.	Perihelion Passage.	π	ω	☊
				GR. M. T.	° ′ ″	° ′ ″	° ′ ″
a	1892 I...	Swift..........	March 7.....	April 6.66545	265 27 29.1	24 31 59.4	240 55 29.7
b	IV...	Spitaler.......	March 18.....	June 30.90209	276 10 56.6	172 03 32.9	104 07 23.7
c	II...	Denning......	March 18.....	May 11.18321	22 44 16.0	129 18 34.4	253 25 41.6
d	VI...	Brooks........	Aug. 28.....	Dec. 28.0932	157 08 51.1	252 40 52.7	264 27 58.4
e	V.	Barnard.....	Oct. 12.....	Dec. 11.0083	16 52 36.0	170 13 51.1	206 38 44.9
f	III...	Holmes.......	Nov 6.....	June 12.6152	345 35 25.5	13 49 49.6	331 45 35.9
g	1893 I...	Brooks.......	Nov. 19.....	Jan. '93 6.5270	270 54 11.0	85 15 05.4	185 39 05.6

	i	*e*	*q*	Computer.	Reference.
	° ′ ″				
a	38 42 45.9	1.000000	1.026966	Wentworth	A. J. 273
b	14 31 30.8	0.725988	0.886595	Von Hærdtl	A. N. 3112
c	84 42 04.3	1.000000	1.970693	Schorr	A. N. 3089
d	24 47 51.4	1.000000	0.976129	Ristenpart	A. N. 3131
e	31 12 28.1	0.581228	1.42912	Krueger	A. N 3129
f	20 48* 00.0	0.411472	2.135982	Boss	A. J. 283
g	143 52 16.4	1.000000	1.294890	Maitre	A. J. 3838

by Palisa at Vienna, and by Hough at Evanston, Ill., on the same night. Professor Hough observed the comet on Jan. 14 and found it still faint, so that the change must have occurred between Jan. 14 and 16.

COMET *g* 1892.—Discovered on the morning of Nov. 20 by W. R. Brooks at Geneva, N. Y. It was rather bright and had considerable condensation, with which the coma was not quite concentric. It has increased in brightness up to the present time and now has a tail about a degree in length. It will be visible for some months yet.

THE NEGLECTED FIELD OF FUNDAMENTAL ASTRONOMY.*

J. R. EASTMAN.

The limits of this address would scarcely suffice simply to name the problems now under discussion by the more modern methods, without essaying even a cursory review of their importance or their bearing on current scientific investigation;—and yet, from the true astronomical point of view, all these questions are at least secondary to the fundamental problems of finding the true position of the solar system in the stellar universe and determining the relative positions and motions of those stars that, within the range of telescopic vision, compose that universe.

To this latter phase of our science I ask your attention for a few minutes. These problems still lie at the foundation of the "old" astronomy and cannot be relegated to the limbo of useless rubbish or to the museum of curious relics, not even to make room for the newborn astro-physics. On this foundation must rest every astronomical superstructure that hopes to stand the tests of time and of observation, and the precision of the future science depends rigorously upon the accuracy with which this groundwork is laid.

This work was begun in the sixteenth century but, in spite of all the improvements in apparatus and in methods of analysis and research, a really satisfactory result has not yet been reached.

There is no more fascinating phase of the evolution of human thought and skill in the adaptation of means to ends than is found in the development of the mathematical and instrumental means for the determination of the positions and motions of the

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* Extract from an address delivered before the American Association for the advancement of science at its Rochester meeting August 1892.

bodies included in the solar system. Accuracy in astronomical methods and results did not exist, even approximately, until after the revival of practical astronomy in Europe about the beginning of the sixteenth century; and, before the end of that period, the crude instruments of the early astronomers reached their highest perfection in the hands of the skilful genius of Uraniborg.

The invention of the telescope, the application of the pendulum to clocks, the invention of the micrometer, the combination of the telescope with the divided arc of a circle, the invention of the transit circle by Roemer, with many improvements in minor apparatus, distinctly stamp the seventeenth century as a remarkable period of preparation for the achievements of the next century.

From the standpoint of the modern mechanician the instruments at the Greenwich Observatory, in Bradley's time, were very imperfect in design and construction; and yet on the observations obtained by his skill and perseverence, depends the whole structure of modern fundamental astronomy. The use of the quadrant reached its highest excellence under Bradley's management.

The next advance, the real work with divided circles, began at Greenwich in 1811, under the direction of Pond. Since that epoch, theory and observation have held a nearly even course in the friendly race toward that elusive goal, perfection; and the end is not yet. A careful, but independent, determination of the relative right ascensions of the principal stars, supplemented by a rigorous adjustment of such positions with regard to the equinoctial points; and a similar determination of the relative zenith or polar distance of the same bodies, finally referred and adjusted to the equator or the pole,—seem in this brief statement to be, at least, simple problems. If, however, we examine the conditions in detail, the simplicity may not appear so evident; and this characteristic may prove to be one reason why this important branch of astronomical research is now so generally neglected.

In the first place, it must be understood that such an investigation cannot be completed in a few months. At least *two* and preferably *three* years' work in observing are necessary to secure good results. Skilled observers, and not more than two with the same instrument, are absolutely necessary. Such work can not be confided to students or beginners in the art of observing, or to observers who have acquired the habit of anticipating the transit of a star. The telescope and the circles, the objective and the micrometer, the clock and the level must be of the best quality, for imperfections in any of these essentials render the best results impossible. A thoroughly good astronomical clock is the rarest instrument in the astronomer's collection. It is not sufficient that a clock should have a uniform daily rate, the rate should be uniform for any number of minor periods during the twenty-four hours. The absolute personal error in observing transits should be determined at least twice a week, and when it is not well established it should be found every day. The level error should be found every two hours and the greatest care should be exercised in handling this important instrument. The division marks should not be etched on the level tube unless the values of the divisions are frequently examined, for, sooner or later, such tubes become deformed on account of the broken surface and are then worthless.

In the determination of zenith distances the effect of refraction plays such an important part that no work can rightly claim to be fundamental until the local refraction has been carefully investigated and special corrections to the standard tables, if necessary, have been deduced for each observing station. The ordinary mode of observing temperatures is quite inadequate to the importance of the phenomena. These observations should be made as near as possible in the mass of air through which the objective of the telescope is moved and also in the opening in the roof and the sides of the observing room where the outside air comes in contact with that in the building. The thermometers should all be mounted so that they may be whirled in that portion of the air where the temperature is desired, and they should be tested at least once a year to determine the change in the position of the zero of the scale. But a complete list of the things to be done, and of the errors to be avoided, are too voluminous for this occasion and are not necessary to show the complex character of the problem; — the suggestions, already made, must suffice.

For many years an immense number of observations of the larger or the so-called standard stars have been made at the principal observatories, for different purposes and with varying degrees of accuracy, but it is not certain that the work of the last thirty years, with all the advantages of improved apparatus, has resulted in more exact determination of even the *relative* right ascensions of such stars. There can be no doubt that the chronographic registration of star transits has given more accurate results for the smaller stars, but I think it is equally true that, in the case of first and second magnitude stars, at least, no improvement has been made in accuracy.

(TO BE CONTINUED.)

ASTRO-PHYSICS.

GRATINGS IN THEORY AND PRACTICE.*

HENRY A. ROWLAND.†

PART I.

It is not my object to treat the theory of diffraction in general but only to apply the simplest ordinary theory to gratings made by ruling grooves with a diamond on glass or metal. This study I at first made with a view of guiding me in the construction of the dividing engine for the manufacture of gratings, and I have given the present theory for years in my lectures. As the subject is not generally understood in all its bearings I have written it for publication.

Let p be the virtual distance reduced to vacuo through which a ray moves. Then the effect at any point will be found by the summation of the quantity

$$A \cos b(p - Vt) + B \sin b(p - Vt)$$

in which $b = \frac{2\pi}{l}$, l being the wave-length, V is the velocity reduced to vacuo, and t is the time. Making $\theta = \tan^{-1} \frac{A}{B}$ we can write this

$$\sqrt{A^2 + B^2} \sin [\theta + b(p - Vt)].$$

The energy or intensity is proportional to $(A^2 + B^2)$

Taking the expression

$$(A + iB)e^{-ib(p - Vt)},$$

when $i = \sqrt{-1}$, its real part will be the previous expression for the displacement. Should we use the exponential expression instead of the circular function in our summation we see that we can always obtain the intensity of the light by multiplying the final result by itself with $-i$ in place of $+i$, because we have

$$(A + iB)e^{-ib(p - Vt)} \times (A - iB)e^{ib(p - Vt)} = A^2 + B^2$$

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* Communicated by the author.

† I am much indebted to Dr. Ames for looking over the proofs of this paper and correcting some errors. In the paper I have, in order to make it complete, given some results obtained previously by others, especially by Lord Rayleigh. The treatment is, however, new, as well as many of the results. My object was originally to obtain some guide to the effect of errors in gratings so that in constructing my dividing engine I might prevent their appearance if possible.

In cases where a ray of light falls on a surface where it is broken up, it is not necessary to take account of the change of phase at the surface but only to sum up the displacement as given above.

In all our problems let the grating be rather small compared with the distance of the screen receiving the light so that the displacements need not be divided into their components before summation.

Let the point x', y', z' be the source of light, and at the point x, y, z let it be broken up and at the same time pass from a medium of index of refraction I′ to one of I. Consider the disturbance at a point x'', y'', z'' in the new medium. It will be

$$e^{-ib(I\rho + I'p - Vt)}$$

where

$$\rho^2 = x''^2 + y''^2 + z''^2 + x^2 + y^2 + z^2 - 2(xx'' + yy'' + zz'').$$
$$p^2 = x'^2 + y'^2 + z'^2 + x^2 + y^2 + z^2 - 2(xx' + yy' + zz').$$

Let the point x, y, z be near the origin of co-ordinates as compared with x', y', z' or x'', y'', z'' and let α, β, γ and α', β', γ' be the direction cosines of ρ and p. Then, writing

$$\begin{aligned} R &= I'\sqrt{x'^2 + y'^2 + z'^2} + I\sqrt{x''^2 + y''^2 + z''^2} \\ \lambda &= I\alpha + I'\alpha' \\ \mu &= I\beta + I'\beta' \\ \nu &= I\gamma + I'\gamma' \end{aligned}$$

we have, for the elementary displacement,

$$e^{-ib[R - Vt - \lambda x - \mu y - \nu z + \kappa r^2]}$$

$$\text{where } \kappa = \tfrac{1}{2}\left[\frac{I'}{\sqrt{x'^2 + y'^2 + z'^2}} + \frac{I}{\sqrt{x''^2 + y''^2 + z''^2}}\right]$$

$$\text{and } r^2 = x^2 + y^2 + z^2.$$

This equation applies to light in any direction. In the special case of parallel light, for which $\kappa = 0$, falling on a plane grating with lines in the direction of z, one condition will be that this expression must be the same for all values of z.

Hence $\nu = 0$.

If N is the order of the spectrum and a the grating space we shall see further on that we also have the condition

$$ba\mu = 2\pi N = \frac{2\pi a}{l}\mu$$

The direction of the diffracted light will then be defined by the equations

$$\alpha'^2 + \beta'^2 + \gamma'^2 = 0$$
$$\mathrm{I}\gamma + \mathrm{I}'\gamma' = 0$$
$$\mathrm{I}\beta + \mathrm{I}'\beta' = \frac{l}{a}\,\mathrm{N}$$

Whence

$$\mathrm{I}'\alpha' = \mathrm{I}\sqrt{\alpha^2 + 2\frac{l}{\mathrm{I}a}\mathrm{N}\beta - \frac{l^2\mathrm{N}^2}{\mathrm{I}^2a^2}}$$
$$\mathrm{I}'\beta' = \frac{l}{a}\mathrm{N} - \mathrm{I}\beta$$
$$\mathrm{I}'\gamma' = -\,\mathrm{I}\gamma$$

In the ordinary case where the incident and diffracted rays are perpendicular to the lines of the grating, we can simplify the equations somewhat.

Let φ be the angle of incidence and ψ of diffraction as measured from the positive direction of X.

$$\lambda = \mathrm{I}'\cos\varphi + \mathrm{I}\cos\psi$$
$$\frac{l}{a}\,\mathrm{N} = \mu = \mathrm{I}'\sin\varphi + \mathrm{I}\sin\psi$$
$$b = \frac{2\pi}{l}$$ where l is the wave-length in vacuo.

In case of the reflecting grating $\mathrm{I} = \mathrm{I}'$ and we can write

$$\lambda = \mathrm{I}\{\cos\varphi + \cos\psi\}$$
$$\frac{l}{a}\mathrm{N} = \mu = \mathrm{I}\{\sin\varphi + \sin\psi\}$$

This is only a very elementary expression as the real value would depend on the nature of the obstacle, the angles, etc., but it will be sufficient for our purpose.

The disturbance due to any grating or similar body will then be very nearly

$$\int\!\!\int e^{-ib[\mathrm{R} - \mathrm{V}t - \lambda x - \mu y - \nu z + \varkappa(x^2 + y^2 + z^2)]}ds.$$

where ds is a differential of the surface. For parallel rays, $\varkappa = 0$.

PLANE GRATINGS.

In this case the integration can often be neglected in the direction of z and we can write for the disturbance in case of parallel rays,

$$e^{-ib(\mathrm{R}-\mathrm{V}t)}\int\!\!\int e^{-ib[-\lambda x - \mu y]}ds.$$

CASE I.—SIMPLE PERIODIC RULING.

Let the surface be divided up into equal parts in each of which one or more lines or grooves are ruled parallel to the axis of z.

The integration over the surface will then resolve itself into an integration over one space and a summation with respect to the number of spaces. For in this case we can replace y by $na + y$ where a is the width of a space and the displacement becomes

$$e^{-ib(R - Vt)} \sum e^{+ib\mu an} \int\int e^{+ib(\lambda x + \mu y)} ds$$

$$\text{but} \quad \sum_0^{n-1} e^{+ib\mu an} = e^{+i\frac{n-1}{2}ba\mu} \frac{\sin n\dfrac{ba\mu}{2}}{\sin\dfrac{ba\mu}{2}}$$

Multiplying the disturbance by itself with $-i$ in place of $+i$ we have for the light intensity

$$\left\{\frac{\sin n\dfrac{ba\mu}{2}}{\sin\dfrac{ba\mu}{2}}\right\}^2 \left[\int e^{-ib(\lambda x + \mu y)} ds\right]\left[\int e^{+ib(\lambda x + \mu y)} ds\right]$$

The first term indicates spectral lines in positions given by the equation

$$\sin\frac{ba\mu}{2} = 0$$

with intensities given by the last integral. The intensity of the spectral lines then depends on the form of the groove as given by the equation $x = f(y)$ and upon the angles of incidence and diffraction. The first factor has been often discussed and it is only necessary to call attention to a few of its properties.

When $ba\mu = 2\pi N$, N being any whole number, the expression becomes n^2. On either side of this value the intensity decreases until $nba\mu' = 2\pi N$, when it becomes 0.

The spectral line then has a width represented by $\mu' - \mu'' = 2\frac{\mu}{n}$ nearly; on either side of this line smaller maxima exist too faintly to be observed. When two spectral lines are nearer together than half their width, they blend and form one line. The defining power of the spectroscope can be expressed in terms of the quotient of the wave-length by the difference of wave-length of two lines that can just be seen as divided. The defining power is, then,

$n\mathrm{N}$[*] $= na\dfrac{\mu}{l}$

Now na is the width of the grating. Hence, using a grating at a given angle, the defining power is independent of the number of lines to the inch and only depends on the width of the grating and the wave-length. According to this, the only object of ruling many lines to the inch in a grating is to separate the spectra so that, with a given angle, the order of spectrum shall be less.

Practically the gratings with few lines to the inch are much better than those with many, and hence have *better* definition at a given angle than the latter except that the spectra are more mixed up and more difficult to see.

It is also to be observed that the defining power increases with shorter wave-lengths, so that it is three times as great in the ultra-violet as in the red of the spectrum. This is of course the same with all optical instruments such as telescopes and microscopes.

The second term which determines the strength of the spectral lines will, however, give us much that is new.

First let us study the effect of the shape of the groove on the brightness. If N is the order of the spectrum and a the grating space we have

$$\mu = \mathrm{I}(\sin\varphi + \sin\psi) = \frac{\mathrm{N}l}{a}$$

since $\sin\dfrac{ba\mu}{2} = 0$.

and the intensity of the light becomes proportional to

$$\left[\int\!\!\int e^{i2\pi(\frac{\lambda}{l}x + \frac{\mathrm{N}}{a}y)}\,ds\right]\left[\int\!\!\int e^{-i2\pi(\frac{\lambda}{l}x + \frac{\mathrm{N}}{a}y)}\,ds\right]$$

It is to be noted that this expression is not only a function of N but also of l, the wave-length. This shows that the intensity in general may vary throughout the spectrum according to the wave-length and that the sum of the light in any one spectrum is not always white light.

This is a peculiarity often noticed in gratings. Thus one spectrum may be almost wanting in the green, while another may contain an excess of this color; again there may be very little blue in one spectrum while very often the similar spectrum on the other side may have its own share and that of the other one also. For this reason I have found it almost impossible to predict what the ultra red spectrum may be, for it is often weak even where the visible spectrum is strong.

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[*] An expression of Lord Rayleigh's.

The integral may have almost any form although it will naturally tend to be such as to make the lower orders the brightest when the diamond rules a single and simple groove. When it rules several lines or a compound groove, the higher orders may exceed the lower in brightness and it is mathematically possible to have the grooves of such a shape that, for given angles, all the light may be thrown into one spectrum.

It is not uncommon, indeed very easy, to rule gratings with immensely bright first spectra, and I have one grating where it seems as if half the light were in the first spectrum on one side. In this case there is no reflection of any account from the grating held perpendicularly: indeed to see one's face, the plate must be held at an angle, in which case the various features of the face are seen reflected almost as brightly as in a mirror but drawn out into spectra. In this case all the other spectra and the central image itself are very weak.

In general it would be easy to prove from the equation that want of symmetry in the grooves produces want of symmetry in the spectra, a fact universally observed in all gratings and one which I generally utilize so that the light may be concentrated in a few spectra only.

EXAMPLE I. SQUARE GROOVES.

When the light falls nearly perpendicularly on the plate, we need not take the sides into account but only sum up the surface of the plate and the bottom of the groove. Let the depth be X and the width equal to $\frac{a}{m}$.

The intensity then becomes proportional to

$$\frac{1}{N^2}\sin^2\pi\frac{N}{m}\sin^2\pi\frac{\lambda}{l}X$$

This vanishes when

$$N = m,\ 2m,\ 3m, \text{ etc.}$$

$$\text{or,}\quad \frac{\lambda X}{l} = 0,\ 1,\ 2,\ 3, \text{ etc.}$$

The intensity of the central light, for which $N = 0$, will be

$$\frac{\pi^2}{m^2}\sin^2\left(\pi\frac{\lambda}{l}X\right).$$

This can be made to vanish for only one angle for a given wave-length. Therefore, the central image will be colored and the color will change with the angle, an effect often observed in actual gratings. The color ought to change, also, on placing the grating in a liquid of different index of refraction since λ contains I, the index of refraction.

It will be instructive to take a special case, such as light falling perpendicularly on the plate. For this case

$\varphi = 0$, $\lambda = \mathrm{I}(1 + \cos\psi)$ and $\mu = \mathrm{I}\sin\psi = \dfrac{\mathrm{N}l}{a}$.

$$\text{Hence, } \lambda = \mathrm{I}\left\{1 + \sqrt{1 - \left(\frac{\mathrm{N}l}{a\mathrm{I}}\right)^2}\right\}.$$

The last term in the intensity will then be

$$\sin^2\left\{\pi \mathrm{X}\mathrm{I}\left[\frac{1}{l} + \sqrt{\frac{1}{l^2} - \left(\frac{\mathrm{N}}{a\mathrm{I}}\right)^2}\right]\right\}.$$

As an example, let the green of the second order vanish. In this case, $l = .00005$. $\mathrm{N} = 2$. Let $a = .0002$ c.m. and $\mathrm{I} = 1$.

$$\text{Then, } \mathrm{X}\left[20000. + \sqrt{(20000)^2 - (10000)^2}\right] = n.$$

$$\text{Whence, } \mathrm{X} = \frac{n}{37300.}$$

where n is any whole number. Make it 1.

Then the intensity, as far as this term is concerned, will be as follows:

	Minima where Intensity is 0. Wave-lengths.		Maxima where Intensity is 1 Wave-lengths.		
1st spec.	.0000526	.0000268	.0001000	.00003544	.00002137
2nd "	.0000500	.0000266	.0000833	.00003463	.00002119
3rd "	.0000462	.0000263	.0000651	.00003343	.00002089
4th "	.0000416	.0000259	.0000499	.00003169	.00002050
5th "	etc.		etc.	etc.	

The central light will contain the following wave-lengths as a maximum:

.0001072 .00003575 .0000214, etc.

Of course it would be impossible to find a diamond to rule a rectangular groove as above and the calculations can only be looked upon as a specimen of innumerable light distributions according to the shape of groove.

Every change in position of the diamond gives a different light distribution and hundreds of changes may be made every day and yet the same distribution will never return, although one may try for years.

EXAMPLE 2.—TRIANGULAR GROOVE.

Let the space a be cut into a triangular groove, the equations of the sides being $x = -cy$, and $x = c'(y - a)$, the two cuttings coming together at the point $y = u$. Hence we have $-cu = c'(u - a)$, and $ds = dy\sqrt{1 + c^2}$, or $dy\sqrt{1 + c'^2}$. Hence the intensity is proportional to

$$I^2 \left\{ \frac{1 + c^2}{(\mu - c\lambda)^2} \sin^2 \frac{\pi u(\mu - c\lambda)}{l} + \frac{1 + c'^2}{(\mu + c'\lambda)^2} \sin^2 \frac{\pi(a - u)(\mu + c'\lambda)}{l} \right.$$

$$+ \frac{\sqrt{(1 + c^2)(1 + c'^2)}}{(\mu - cy)(\mu + c'\lambda)} \sin \frac{\pi u(\mu - c\lambda)}{l} \sin \frac{\pi(a - u)(\mu + c'\lambda}{l}$$

$$\left. \cos \frac{\pi}{l}[(\mu + c'\lambda)(a - u) - n(\mu - c\lambda)] \right\}$$

This expression is not symmetrical with respect to the normal to the grating, unless the groove is symmetrical, in which case $c = c'$ and $u = \frac{a}{2}$.

In this case, as in the other, the colors of the spectrum are of variable intensity, and some of them may vanish as in the first example, but the distribution of intensity is in other respects quite different.

CASE 2.—MULTIPLE PERIODIC RULING.

Instead of having only one groove ruled on the plate in this space a, let us now suppose that a series of similar lines are ruled.

We have, then, to obtain the displacement by the same expression as before, that is

$$\frac{\sin n \frac{ba\mu}{2}}{\sin \frac{ba\mu}{2}} \int e^{ib(\lambda n + \mu y)} ds,$$

except that the last integral will extend over the whole number of lines ruled within the space a.

In the spaces a let a number of equal grooves be ruled commencing at the points $y = 0$, y_1, y_2, y_3, etc., and extending to the points w, $y_1 + w$, $y_2 + w$, etc. The surface integral will then be divided into portions from w to y_1, from $y_1 + w$, to y_2, etc., on the original surface of the plate for which $x = 0$, and from w to 0, from $y_1 + w$ to y_1, etc., for the grooves.

The first series of integrals will be

$$\int e^{ib\mu y}dy = \left\{\frac{1}{ib\mu}\right\}\left\{-e^{ib\mu w}+e^{ib\mu y_1}-e^{ib\mu(y_1+w)}+e^{ib\mu y_2}-\text{etc.}\right\}$$

$$=\frac{1}{ib\mu}\left\{-e^{ib\mu w}+\left(1-e^{ib\mu w}\right)\left(e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right)+e^{ibua}\right\}$$

But, $e^{ibua}=1$ since $b\mu a=0$ for any maximum, and thus the integral becomes

$$\frac{1-e^{ib\mu w}}{ib\mu}\left\{1+e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right\}$$

The second series of integrals will be

$$\int_0^w e^{ib(\lambda n+\mu y)}ds.\left\{1+e^{ib\mu y_1}+\text{etc.}\right\}$$

The total integral will then be

$$\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2}}\left[\frac{1-e^{ib\mu w}}{ib\mu}+\int_0^w e^{ib(\lambda x+\mu y)}ds\right]\left[1+e^{ib\mu y_1}+e^{ib\mu y_2}+\text{etc.}\right]$$

As before, multiply this by the same with the sign of i changed to get the intensity.

EXAMPLE I.—EQUAL DISTANCES.

The space, a, contains $n'-1$ equidistant grooves, so that $y_1=y_2-y_1=\text{etc.},=\frac{a}{n'}$.

$$\sum_0^{n'-1} e^{ibu\frac{a}{n'}n}=e^{iba\mu}\frac{\sin\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2n'}}$$

Hence the displacement becomes

$$\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2n'}}\left[\frac{1-e^{ib\mu w}}{ib\mu}+\int_0^w e^{ib(\lambda x+\mu y)}ds.\right]$$

As the last term is simply the integral over the space $\frac{a}{n'}$, in a different form from before, this is a return to the form we previously had except that it is for a grating of nn' lines instead of n lines, the grating space being $\frac{a}{n'}$.

EXAMPLE II.—TWO GROOVES.

$$1 + e^{ib\mu y_1} = 2e^{\frac{ib\mu y_1}{2}} \cos \frac{b\mu y_1}{2}$$

But $ba\mu = 2N\pi$. Hence this becomes

$$2e^{i\pi N\frac{y_1}{a}} \cos \pi N \frac{y_1}{a}.$$

The square of the last term is a factor in the intensity. Hence the spectrum will vanish when we have

$$N\frac{y_1}{a} = \tfrac{1}{2}, \tfrac{3}{2}, \tfrac{5}{2}, \text{etc.*}$$

$$\text{or, } N = \frac{1}{2}\frac{a}{y_1}, \frac{3}{2}\frac{a}{y_1}, \frac{5}{2}\frac{a}{y_1}, \text{etc.}$$

Thus when $\frac{a}{y_1} = 2$, the 1st, 3d, etc., spectra will disappear making a grating of twice the number of lines to the c.m.

When $\frac{a}{y_1} = 4$, the 2d, 6th, 10th, etc, spectra disappear. When $\frac{a}{y_1} = 6$, the 3d, 9th, etc., spectra disappear.

The case in which $\frac{a}{y_1} = 4$, as Lord Rayleigh has shown, would be very useful as the second spectrum disappears leaving the red of the first and the ultra violet of the third without contamination by the second. In this case two lines are ruled and two left out. This would be easy to do but the advantages would hardly pay for the trouble owing to the following reasons: Suppose the machine was ruling 20,000 lines to the inch. Leaving out two lines and ruling two would reduce the dispersion down to a grating with 5,000 lines to the inch. Again, the above theory assumes that the grooves do not overlap. Now I believe that in nearly, if not all, gratings with 20,000 lines to the inch the whole surface is cut away and the grooves overlap. This would cause the second spectrum to appear again after all our trouble.

Let the grooves be nearly equidistant, one being slightly displaced. In this case $y_1 = \frac{a}{2} + v$.

$$\cos^2 \pi \frac{Ny_1}{a} = \left(\cos \frac{\pi N}{2} \cos \frac{\pi N v}{a} - \sin \frac{\pi N}{2} \sin \frac{\pi N v}{a}\right)^2$$

For the even spectra this is very nearly unity, but for the odd it becomes

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* A thorem of Lord Rayleigh's.

$$\left(\pi N\frac{v}{a}\right)^2$$

Hence the grating has its principal spectra like a grating of space $\frac{a}{2}$, but there are still the intermediate spectra due to the space a, and of intensities depending on the *squares* of the order of spectrum, and the squares of the relative displacement, a law which I shall show applies to the effect of all errors of the ruling.

This particular effect was brought to my attention by trying to use a tangent screw on the head of my dividing engine to rule a grating with say 28,872 lines to the inch, when a single tooth gave only 14,436 to the inch. However carefully I ground the tangent screw I never was able to entirely eliminate the intermediate spectra due to 14,436 lines, and make a pure spectrum due to 28,872 lines to the inch, although I could nearly succeed.

EXAMPLE 3.—ONE GROOVE IN m MISPLACED.

Let the space a contain m grooves equidistant except one which is displaced a distance v. The displacement is now proportional to

$$1 + e^{ib\mu\frac{a}{m}} + e^{2ib\mu\frac{a}{m}} + \text{etc.} + e^{ib\mu\left(p\frac{a}{m} + v\right)} + \text{etc.} + e^{ib\mu\frac{m-1}{m}a}$$

$$= e^{ib\mu\frac{m-1}{2m}a}\left\{\frac{\sin\frac{b\mu a}{2}}{\sin\frac{b\mu a}{2m}} + ib\mu v\, e^{ib\mu a\frac{2p-m+1}{2m}}\right\}$$

Multiplying this by itself with $-i$ in place of $+i$, and adding the factors in the intensity, we have the whole expression for the intensity. One of the terms entering the expression will be

$$\frac{\sin n\frac{b\mu a}{2}}{\sin\frac{ba\mu}{2m}}\;\frac{\sin n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2}}\;\sin\frac{ba\mu}{2}\,\frac{2p-m+1}{m}$$

Now the first two terms have finite values only around the points $\frac{ba\mu}{2} = mN\pi$, where mN is a whole number. But $2p - m + 1$ is also a whole number, and hence the last term is zero at these points. Hence the term vanishes and leaves the intensity, omitting the groove factor,

$$\frac{\sin^2 n\frac{ba\mu}{2}}{\sin\frac{ba\mu}{2m}} + (b\mu v)^2\frac{\sin^2 n\frac{ba\mu}{2}}{\sin^2\frac{ba\mu}{2}}$$

The first term gives the principle spectra as due to a grating space of $\frac{a}{m}$ and number of lines nm as if the grating were perfect. The last term gives entirely new spectra due to the grating space, a, and with lines of breadth due to a grating of n lines and intensities equal to $(b\mu v)^2$.

Hence, when the tangent screw is used on my machine for 14,436 lines to the inch, there will still be present weak spectra due to the 14,436 spacing although I should rule say 400 lines to the *mm*. This I have practically observed also.

The same law holds as before that the relative intensity in these subsidiary spectra varies as the square of the order of the spectrum and the square of the deviation of the line, or lines from their true position.

So sensitive is a dividing engine to periodic disturbances that all the belts driving the machine must never revolve in periods containing an aliquot number of lines of the grating; otherwise they are sure to make spectra due to their period.

As a particular case of this section we have also to consider

PERIODIC ERRORS OF RULING.—THEORY OF "GHOSTS."

In all dividing engines the errors are apt to be periodic due to "drunken" screws, eccentric heads, imperfect bearings, or other causes. We can then write

$$y = n_0 a + a_1 \sin(e_1 n) + a_2 \sin(e_2 n), + \text{etc.}$$

The quantities e_1, e_2, etc., give the periods, and a_1, a_2, etc., the amplitudes of the errors. We can then divide the integral into two parts as before, an integral over the groove and spaces and a summation with respect to the numbers.

$$\Sigma\int_{y'}^{y''} e^{-ib(\lambda x+\mu y)}ds = \Sigma e^{-ib\mu y}\int_0^{y''-y'} e^{-ib(\lambda n+\mu y)}ds \,.$$

It is possible to perform these operations exactly, but it is less complicated to make an approximation, and take $y'' - y' = a$, a constant as it is very nearly in all gratings. Indeed the error introduced is vanishingly small. The integral which depends on the shape of the groove, will then go outside the summation sign and we have to perform the summation

$$\Sigma\, e^{-ib\mu\{a_0 n + a_1 \sin e_1 n + a_2 \sin e_2 n + \text{etc.}\}}$$

Let J_n be a Bessel's function. Then

$$\cos(u \sin \varphi) = J_0(u) + 2[J_2(u) \cos_2 \varphi + J_4(u) \cos_4 \varphi + \text{etc.}$$

$$\sin (u \sin \varphi = \qquad 2(J_1(u) \sin \varphi + J_3(u) \sin_3 \varphi + \text{etc.}$$

But $e^{-iu \sin \varphi} = \cos(u \sin \varphi) - i \sin(u \sin \varphi.)$

Hence the summation becomes

$$\Sigma \left\{ \begin{array}{ll} e^{-ib\mu a_0 n} & \\ \times\, [J_0(b\mu a_1) + 2(-iJ_1(b\mu a_1) \sin e_1 n + J_2(b\mu a_1) \cos 2e_1 n - \text{etc.})] & \\ \times\, [J_0(b\mu a_2) + 2(-iJ_1(b\mu a_2) \sin e_2 n + J_2(b\mu a_2) \cos 2e_1 n - \text{etc.})] & \\ \times\, [J_0(b\mu a_3) + \text{etc.} &)] \\ \times\, [\text{etc.} & \end{array} \right.$$

CASE I.—SINGLE PERIODIC ERROR.

In this case only a_0 and a_1 exist. We have the formula

$$\Sigma_0^{n-1} e^{-ipn} = e^{-i\frac{n-1}{2}p} \frac{\sin \frac{pn}{2}}{\sin \frac{p}{2}}$$

Hence the expression for the intensity becomes

$$\left\{ J_0(b\mu a_1) \frac{\sin n \frac{b\mu a_0}{2}}{\sin \frac{b\mu a_0}{2}} \right\}^2 + J_1^2(b\mu a_1) \left\{ \left(\frac{\sin n \frac{b\mu a_0 + e_1}{2}}{\sin \frac{b\mu a_0 + e_1}{2}} \right)^2 + \left(\frac{\sin n \frac{b\mu a_0 - e_1}{2}}{\sin \frac{b\mu a_0 - e_1}{2}} \right)^2 \right\} + \text{etc.}$$

As n is large, this represents various very narrow spectral lines whose light does not overlap and thus the different terms are independent of each other. Indeed in obtaining this expression the products of quantities have been neglected for this reason because one or the other is zero at all points. These lines are all alike in relative distribution of light and their intensities and positions are given by the following table.

Places.	*Intensities.*	*Designations.*
$\mu = \frac{2\pi N}{ba_0}$	$J_0^2(b\mu a_1)$	Primary lines.
$\mu_1 \doteq \mu \pm \frac{e_1}{ba_0}$	$J_1^2(b\mu_1 a_1)$	Ghosts of 1st order.
$\mu_2 = \mu \pm \frac{2e_1}{ba_0}$	$J_2^2(b\mu_1 a_2)$	Ghosts of 2d order.
$\mu_3 = \mu \pm \frac{3e_1}{ba_0}$	$J_3^2(b\mu_3 a_1)$	Ghosts of 3d order.
etc.	etc.	etc.

Hence the light which would have gone into the primary line now goes to making the ghosts, so that the total light in the line and its ghosts is the same as in the original without ghosts.

The relative intensities of the ghosts as compared with the primary line is

$$\frac{J_n^2(b\mu a_1)}{J_0^2(b\mu a_1)}$$

This for very weak ghosts of the first, second, third, etc., order, becomes

$$\left(\pi N \frac{a_1}{a_0}\right)^2, \quad \frac{1}{2}\left(\pi N \frac{a_1}{a_0}\right)^4, \quad \frac{1}{6}\left(\pi N \frac{a_1}{a_0}\right)^6, \text{ etc.}$$

The intensity of the ghosts of the first order varies as the square of the order of the spectrum and as the square of the relative displacement as compared with the grating space a_0. This is the same law as we before found for other errors of ruling, and it is easy to prove that it is general. Hence

The effect of small errors of ruling is to produce diffused light around the spectral lines. This diffused light is subtracted from the light of the primary line, and its comparative amount varies as the square of the relative error of ruling and the square of the order of the spectrum.

Thus the effect of the periodic error is to diminish the intensity of the ordinary spectral lines (primary lines) from the intensity 1 to $J_0^2(b\mu a_1)$, and surround it with a symmetrical system of lines called ghosts, whose intensities are given above.

When the ghosts are very near the primary line, as they nearly always are in ordinary gratings ruled on a dividing engine with a large number of teeth in the head of the screw, we shall have

$$J_1^2 ba_1\left(\mu + \frac{e_1}{ba_0}\right) + J_1^2 ba_1\left(\mu - \frac{e_1}{ba_0}\right) = 2J_1^2 ba_1 \mu \text{ nearly.}$$

Hence the total light is by a known theorem,

$$J_0^2 + 2[J_1^2 + J_2^2 + \text{etc.} = 1.$$

Thus, in all gratings, the intensity of the ghosts as well as the diffused light increases rapidly with the order of the spectrum. This is often marked in gratings showing too much crystalline structure. For the ruling brings out the structure and causes local difference of ruling which is equivalent to error of ruling as far as diffused light is concerned.

For these reasons it is best to get defining power by using broad gratings and a low order of spectra although the increased perfection of the smaller gratings makes up for this effect in some respects.

There is seldom advantage in making both the angle of incidence and diffraction more than 45°, but, if the angle of incidence is 0, the other angle may be 60°, or even 70°, as in concave gratings. Both theory and practice agree in these statements.

Ghosts are particularly objectionable in photographic plates, especially when they are exposed very long. In this case ghosts may be brought out which would be scarcely visible to the eye.

As a special case, take the following numerical results:

$$\begin{array}{ccccccccccc}
N & = & & 1 & & & 2 & & & 3 & \\
\frac{a_1}{a_0} & = & \frac{1}{25}, & \frac{1}{50}, & \frac{1}{100} & \frac{1}{25}, & \frac{1}{50}, & \frac{1}{100} & \frac{1}{25}, & \frac{1}{50}, & \frac{1}{100} \\
\left(\pi N \frac{a_1}{a_0}\right)^2 & = & \frac{1}{63}, & \frac{1}{252}, & \frac{1}{1008} & \frac{1}{16}, & \frac{1}{63}, & \frac{1}{252} & \frac{1}{7}, & \frac{1}{28}, & \frac{1}{102}
\end{array}$$

In a grating with 20,000 lines to the inch, using the third spectrum, we may suppose that the ghosts corresponding to $\frac{a_1}{a_0} = \frac{1}{50}$ will be visible and those for $\frac{a_1}{a_0} = \frac{1}{25}$ very troublesome. The first error is $a_1 = \frac{1}{1000000}$ in. and the second $a_1 = \frac{1}{500000}$ in. Hence a periodic displacement of one millionth of an inch will produce visible ghosts and one five hundred thousandth of an inch will produce ghosts which are seen in the second spectrum and are troublesome in the third. With very bright spectra these might even be seen in the first spectrum. Indeed an over exposed photographic plate would readily bring them out.

When the error is very great, the primary line may be very faint or disappear altogether, the ghosts to the number of twenty or fifty or more being often more prominent than the original line. Thus, when

$$b\mu a_1 = 2.405,\ 5.52,\ 8.65 \text{ etc.} \ = 2\pi N\frac{a_1}{a_0}$$

the primary line disappears. When

$$b\mu a_1 = 0,\ 3.83,\ 7.02 \text{ etc.} \ = 2\pi N\frac{a_1}{a_0},$$

the ghosts of the first order will disappear. Indeed we can make any ghost disappear by the proper amount of error.

Of course, in general

$$J_n = \frac{2(n-1)}{v} J_{n-1} - J_{n-2}.$$

Thus a table of ghosts can be formed readily and we may always tell when the calculation is complete by taking the sum of the light and finding unity.

$2\pi N\frac{a_1}{a_0}$	J_0^2	J_1^2	J_2^2	J_3^2	J_4^2	J_5^2	J_6^2	J_7^2	J_8^2	J_9^2	J_{10}^2	J_{11}^2	J_{12}^2	J_{13}^2	J_{14}^2
0.	1.000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
.2	.980	.010	—	—	—	—	—	—	—	—	—	—	—	—	—
.4	.922	.038	—	—	—	—	—	—	—	—	—	—	—	—	—
.6	.832	.082	.002	—	—	—	—	—	—	—	—	—	—	—	—
.8	.716	.136	.005	—	—	—	—	—	—	—	—	—	—	—	—
1.0	.586	.194	.012	—	—	—	—	—	—	—	—	—	—	—	—
2.0	.050	.333	.124	.017	.001	—	—	—	—	—	—	—	—	—	—
2.605	.000	.269	.186	.040	.003	—	—	—	—	—	—	—	—	—	—
3	.068	.115	.236	.095	.017	.002	—	—	—	—	—	—	—	—	—
3.832	.162	.000	.162	.176	.065	.013	.002	—	—	—	—	—	—	—	—
4.0	.158	.004	.133	.185	.079	.018	.002	—	—	—	—	—	—	—	—
5.0	.031	.107	.002	.133	.153	.068	.017	.003	—	—	—	—	—	—	—
5.520	.000	.116	etc.												
6.0	.022	.077	.059	.013	.128	.131	.061	.017	.003	—	—	—	—	—	—
7.016	.090	.000	.090	etc.											
8	.029	.055	.013	.085	.011	.035	.114	.103	.050	.016	.003	.001	—	—	—
8.654	.000	.075	etc.												
10.	.060	.002	.065	.003	.048	.055	.002	.047	.101	.091	.051	.022	.011	.009	.022

This table shows how the primary line weakens and the ghosts strengthen as the periodic error increases, becoming 0 at $2\pi N\frac{a'}{a} = 2.405$. It then strengthens and weakens periodically, the greatest strength being transferred to one of the ghosts of higher and higher order as the error increases.

Thus one may obtain an estimate of the error from the appearance of the ghost.

Some of these wonderful effects with 20 to 50 ghosts stronger than the primary line I have actually observed in a grating ruled on one of my machines before the bearing end of the screw had been smoothed. The effect was very similar to these calculated results.

DOUBLE PERIODIC ERROR.

Supposing as before that there is no overlapping of the lines, we have the following:

Places.	*Intensities.*	
$\mu = \frac{2\pi N}{ba_0}$	$\left[J_0(b_1a\mu)\ J_0(ba_2\mu)\right]^2$	Primary line.
$\mu_1 = \mu \pm \frac{e_1}{ba_0}$	$\left[J_1(ba_1\mu_1)\ J_0(ba_2\mu_1)\right]^2$	Ghosts of 1st order.
$\mu_2 = \mu \pm \frac{e_2}{ba_0}$	$\left[J_0(ba_1\mu_2)\ J_1(ba_2\mu_2)\right]^2$	
$\mu_3 = \mu \pm \frac{e_1 \pm e_2}{ba_0}$	$\left[J_1(ba_1\mu_3)\ J_1(ba_2\mu_3)\right]^2$	Ghosts of 2d order.
$\mu_4 = \mu \pm \frac{2e_1}{ba_0}$	$\left[J_2(ba_1\mu_4)\ J_0(ba_2\mu_4)\right]^2$	
$\mu_5 = \mu \pm \frac{2e_2}{ba_0}$	$\left[J_0(ba_1\mu_5)\ J_2(ba_2\mu_5)\right]^2$	
$\mu_6 = \mu \pm \frac{e_1 \pm 2e_2}{ba_0}$	$\left[J_1(ba_1\mu_6)\ J_2(ba_2\mu_6)\right]^2$	Ghosts of 3d order.
$\mu_7 = \mu \pm \frac{2e_1 \pm e_2}{ba_0}$	$\left[J_2(ba_1\mu_7)\ J_1(ba_2\mu_7)\right]^2$	
$\mu_8 = \mu \pm \frac{3e_1}{ba_0}$	$\left[J_0(ba_1\mu_8)\ J_3(ba_2\mu_8)\right]^2$	
$\mu_9 = \mu \pm \frac{3e_2}{ba_0}$	$\left[J_3(ba_2\mu_9)\ J_0(ba_2\mu_9)\right]^2$	
etc.	etc.	

Each term in this table of ghosts simply expresses the fact that each periodic error produces the same ghosts in the same place as if it were the only error, while others are added which are the ghosts of ghosts. The intensities, however, are modified in the presence of these others.

Writing $c_1 = ba_1\mu$ and $c_2 = ba\mu_2$.

The total light is

$$J_0^2(c_1)\,J_0^2(c_2) + \left\{\begin{matrix} 2J_1^2(c_1)\,J_0^2(c_2) \\ +\,2J_0^2(c_1)\,J_1^2(c_2) \end{matrix}\right\} + \left\{\begin{matrix} 2J_2^2(c_1)\,J_0^2(c_2) \\ +\,4J_1^2(c_1)\,J_1^2(c_2) \\ +\,2J_0^2(c_1)\,J_2^2(c_2) \end{matrix}\right\} + \text{etc.}$$

which we can prove to be equal to 1.

Hence the sum of all the light is still unity, a general proposition which applies to any number of errors.

The positions of the lines when there is any number of periodic errors can always be found by calculating first the ghosts due to each error separately; then the ghosts due to these primary ghosts for it as if it were the primary line, and so on *ad infinitum*.

In case the ghosts fall on top of each other the expression for the intensity fails. Thus when $e_2 = 2e_1$, $e_3 = 3e_1$, etc., the formula will need modification. The positions are in this case only those due to a single periodic error, but the intensities are very different.

Places.

$$\begin{array}{ll} \mu = \dfrac{2\pi N}{ba_0} & [J_0(ba_1\mu)J_0(ba_2\mu)]^2 \\ \mu_1 = \mu \pm \dfrac{e_1}{ba_0} & \begin{array}{l} [J_1(ba_1\mu_1)\,J_0(ba_2\mu_1) - J_2(ba_1\mu_1)J_2(ba_2\mu_1) + \text{etc.}]^2 \\ +\,[J_1(ba_1\mu_1)\,J_1(ba_2\mu_1) - J_3(ba_1\mu_1)J({}_1ba_2\mu_1) + \text{etc.}]^2 \end{array} \\ \quad\text{etc.} & \qquad\qquad\text{etc.} \end{array}$$

We have hitherto considered cases in which the error could not be corrected by any change of focus in the objective. It is to be noted, however, that for any given angle and focus, every error of ruling can be neutralized by a proper error of the surface, and that all the results we have hitherto obtained for errors of ruling can be produced by errors of surface, and many of them by errors in size of groove cut by the diamond. Thus ghosts are produced not only by periodic errors of ruling but by periodic waves in the surface, or even by a periodic variation in the depth of ruling. In general, however, a given solution will apply only to one angle and, consequently, the several results will not be identical; in some cases, however, they are perfectly so.

Let us now take up some cases in which change of focus can occur. The term $\varkappa r^2$ in the original formula must now be retained.

Let the lines of the grating be parallel to each other. We can then neglect the terms in z and can write $r^2 = y^2$ very nearly. Hence the general expression becomes

$$\int e^{ib(\lambda x + \mu y - \varkappa y^2)} ds,$$

where $\varkappa$ depends on the focal length. This is supposed to be very large, and hence $\varkappa$ is small.

This integral can be divided into two parts, an integral over the groove and the intervening space, and a summation for all the grooves. The first integral will slightly vary with change in the distance of the grooves apart, but this effect is vanishingly small compared with the effect on the summation, and can thus be neglected. The displacement is thus proportional to

$$\Sigma e^{ib(\mu y - \varkappa y^2)}$$

CASE 1.—LINES AT VARIABLE DISTANCES.

In this case we can write in general

$$y = an + a_1n^2 + a_2n^3 + etc.$$

As κ, a_1, a_2, etc., are small, we have for the displacement, neglecting the products of small quantities,

$$\Sigma e^{ib[\mu(an + a_1n^2 + a_2n^3 + \text{etc.}) - \kappa a^2n^2]}$$

Hence the term a_1n^2 can be neutralized by a change of forms expressed by $\mu a_1 = \kappa a^2$. Thus a grating having such an error will have a different focus according to the angle n, and the change will be + on one side and — on the other.

This error often appears in gratings and, in fact, few are without it.

A similar error is produced by the plate being concave, but it can be distinguished from the above error by its having the focus at the same angle on the two sides the same instead of different.

According to this error, a_1n^2, the spaces between the lines from one side to the other of the grating, increase uniformly in the same manner as the lines in the B group of the solar spectrum are distributed. Fortunately it is the easiest error to make in ruling, and produces the least damage.

The expression to be summed can be put in the form

$$\Sigma e^{ib\mu an}[1 + ib(\mu a_1 - \kappa a^2)n^2 + ib\mu a_2n^3 + ib[\mu a_3 + ib(\mu a_1 - \kappa a^2)^2]n^4 \\ + \text{etc.}]$$

The summation of the different terms can be obtained as shown below, but, in general, the best result is usually sought by changing the focus. This amounts to the same as varying κ until $\mu a_1 - \kappa a^2 = 0$ as before. For the summation we can obtain the following formula from the one already given. Thus

$$\Sigma_0^{n-1} e^{2ipn} = \frac{\sin np}{\sin p} e^{ip(n-1)}$$

Hence

$$\Sigma_0^{n-1} n^m e^{2ipn} = \frac{1}{(2i)^m} e^{ip(n-1)} \left(\frac{d}{dp} + i(n-1)\right)^m \frac{\sin np}{\sin p}$$

When n is very large, writing $\frac{b\mu an}{2} = pn = \pi Nn + q$, we have

$$\Sigma_0^{n-1} n^m e^{2ipn} = \frac{n^{m-1}}{(2i)^m} e^{iq} \left(\frac{d}{dq} + i\right)^m \frac{\sin q}{q}$$

Whence writing

$$\begin{aligned} c &= b(\mu a_1 - \varkappa a^2) \\ c' &= b\mu a_2 \\ c'' &= b[\mu a_3 + ib(\mu a_1 - \varkappa a^2)^2] \\ c''' &= \text{etc.} \end{aligned}$$

the summation is

$$e^{iq}\left\{\begin{array}{r} n + i\left(c\dfrac{n^3}{4} + c'\dfrac{n^4}{8} + c''\dfrac{n^5}{16} + \right) \\ + \left(2c\dfrac{n^3}{4} + 3c'\dfrac{n^4}{8} + 4c''\dfrac{n^5}{16} + \right)\dfrac{d}{dq} \\ - i\left(c\dfrac{n^3}{4} + 3c'\dfrac{n^4}{8} + 6c''\dfrac{n^5}{16} + \right)\dfrac{d^2}{dq^2} \\ - \left(c'\dfrac{n^4}{8} + 4c''\dfrac{n^5}{16} + \right)\dfrac{d^3}{dq^3} \\ + i\left(c''\dfrac{n^5}{16} + \right)\dfrac{d^4}{dq^4} \\ + \text{etc.} \end{array}\right\}\frac{\sin q}{q}$$

$$\begin{aligned} \frac{d}{dq}\frac{\sin q}{q} &= \frac{q\cos q - \sin q}{q^2} \\ \frac{d^2}{dq^2}\frac{\sin q}{q} &= \frac{-2q\cos q + (2-q^2)\sin q}{q^3} \\ \frac{d^3}{dq^3}\frac{\sin q}{q} &= \frac{q(6-q^2)\cos q - (6-3q^2)\sin q}{q^4} \\ \text{etc.} & \qquad\qquad \text{etc.} \end{aligned}$$

These equations serve to calculate the distribution of light intensity in a grating with any error of line distribution suitable to this method of expansion and at any focal length. For this purpose the above summation must be multiplied by itself with $+ i$ in place of $- i$.

The result is for the light intensity

$$\begin{aligned} &\left\{ n\frac{\sin q}{q} + \left(2c\frac{n^3}{4} + 2c\frac{n^4}{8} + \text{etc.}\right)\frac{d}{dq}\frac{\sin q}{q} \right. \\ &\qquad\qquad \left. - \left(c'\frac{n^4}{8} + 4c''\frac{n^5}{16} + \text{etc.}\right)\frac{d^3}{dq^3}\frac{\sin q}{q} + \mathit{etc.} \right\}^2 \\ &+ \left\{ \left(c\frac{n^3}{4} + 3c'\frac{n^4}{8} + \text{etc.}\right)\frac{d^2}{dq^2}\frac{\sin q}{q} \right. \\ &\qquad\qquad \left. - \left(c''\frac{n^5}{16} + \text{etc.}\right)\frac{d^4}{dq^4}\frac{\sin q}{q} + \mathit{etc.} \right\}^2 \end{aligned}$$

As might have been anticipated, the effect of the additional terms is to broaden out the line and convert it into a rather complicated group of lines; as can sometimes be observed with a bad grating. At any given angle the same effect can be produced by variation of the plate from a perfect plane. Likewise the effect of errors in the ruling may be neutralized for a given angle by errors of the ruled surface, as noted in the earlier portions of the paper.

OBSERVATIONS OF NOVA AURIGÆ FROM NOV. 9, TO DEC. 14, 1892.*

W. W. CAMPBELL.

The following observations of the chief nebular line in Nova Aurigæ's spectrum are additional to those already published:

1892.	Grating.	λ	Velocity.
Nov. 9	1st order.	5004.32	— 98 miles.
" 9	2d order.	5004.54	
" 16	1st order.	5004.86	— 80 miles.
" 16	2d order.	5004.94	
" 17	1st order.	5005.07	— 80 miles.
" 17.	2d order.	5004.72	
" 17*	1st order.	5004.89	— 80 miles
" 24	2d order.	5004.49	— 95 miles.
Dec. 13*	1st order.	5004.18	— 107 miles.
" 14*	1st order.	5004.02	— 109 miles.
" 14*	2d order.	5004.22	

The observations marked with an asterisk (*) were made by S. D. Townley, those in December having been secured in my absence from the Observatory. It will be noticed that his measure of Nov. 17 agrees exactly with the mean of the two made by me.

On November 7 I observed the line with our fourth order grating of 14,438 lines to the inch. The line was seen to be eight or nine tenth-meters broad, sloping equally and gradually in both directions. There was not the slightest trace of doubling. Though the dispersion in the fourth order is very nearly three times as great as in the second order, the measures of wavelength can be made more accurately with the latter on account of the greater brightness of the line.

GRAND RAPIDS, Michigan, Dec. 22, 1892.

THE POTSDAM SPECTROGRAPH.*

EDWIN B. FROST.

The instrument was constructed for the express purpose of determining photographically the velocity of stellar motions in the line of sight. Incidentally it fulfils all the functions of a compound star spectroscope adapted for photography.

Preliminary experiments made by Professor Vogel and Dr. Scheiner in 1887 with a merely provisional apparatus demonstrated the entire feasibility of the method, and the spectrograph in its perfected form was applied to the work for which it was devised in September, 1888.

The results of this investigation, which was necessarily brought to a close in May, 1891, by the limitation of the light power of the refractor, are given in detail in Band VII, Theil I, of the *Publicationen des astrophysikalischen Observatoriums zu Potsdam* (Engelmann, Leipzig, 1892).†

We are here chiefly concerned with an explanation of the instrument itself, and shall, for the most part, follow the description given by Professor Vogel in that volume, from which the cuts are taken.

In designing the spectrograph the following essential conditions were laid down: (1) great stability, to secure against flexure of the individual parts, which would be fatal to measurements of displacements; (2) the least possible weight, to prevent flexure of the equatorial; (3) the best adaptation of the dimensions of the optical parts, in order to retain a maximum of light power with the highest available dispersion; (4) an accurate adjustment of the photographic plate in the focal plane of the camera lens, and (5) a reliable means of retaining the image of the star upon the slit.

The first of these conditions was met by the use of steel in most of the parts, yet the weight of the complete instrument is but 12 kg (= 26 lbs.).

The nose-piece of the 12-inch refractor having been removed there is substituted for it a stout connecting frame of three iron rods, the ends of which are provided with screw threads; to these the flat steel base-plate, AA, of the spectrograph (see the small figure) is attached, being retained in position by nust on each

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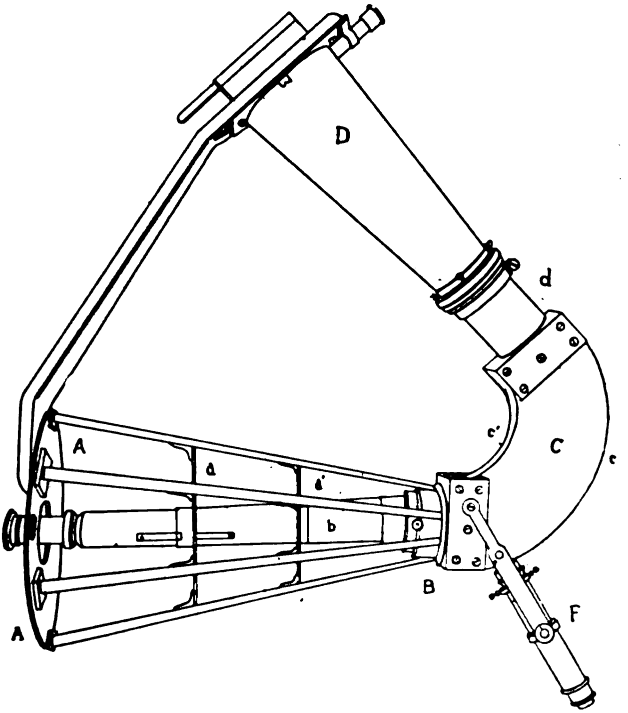
* Communicated by the author.

† Shorter articles will be found in *Monthly Notices*, December, 1891, and June, 1892, the first of which was reprinted in this journal in March, 1892.

side, so that it may be adjusted to be perpendicular to the optical axis of the refractor.

The holes in the base-plate are oval, so as to allow a slight rotation of the whole apparatus and thus permit the slit to be set precisely parallel to the equator. Six steel braces, T shaped in section, are riveted to the base-plate and unite in a stiff ring BB of cast brass.



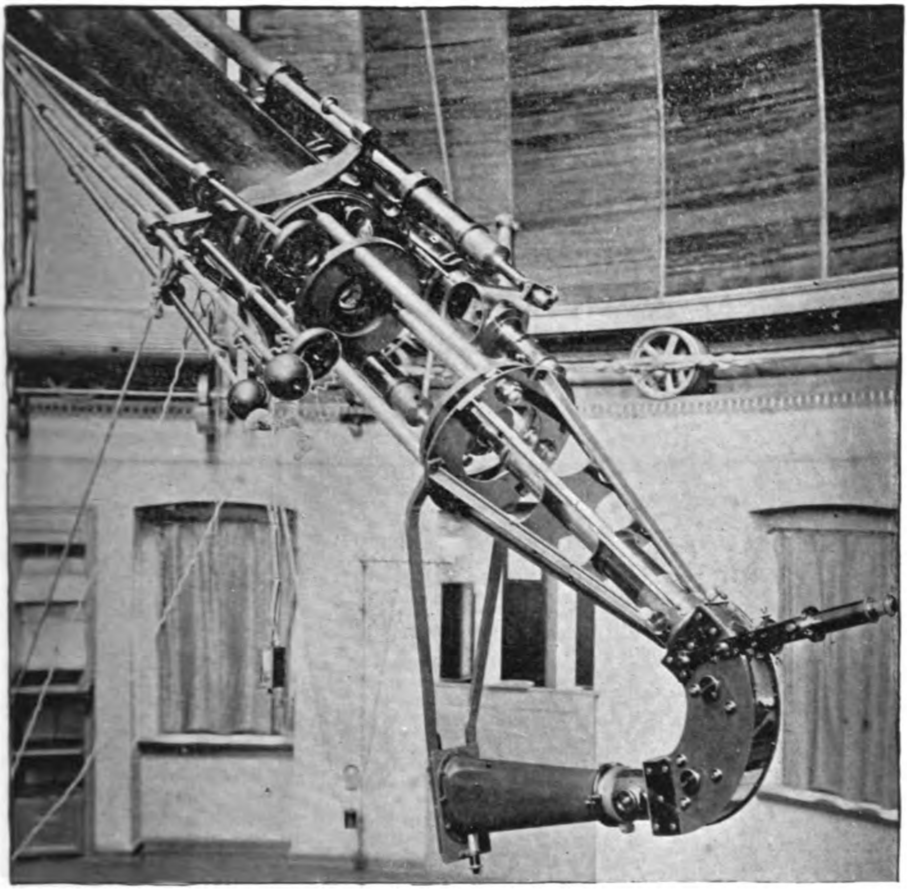
Plates of sheet steel *a* and a^1 add stability, and support cylindrical collars through which the brass collimator-tube may be moved in the direction of its axis by a ratchet and pinion. The amount of this motion may be accurately read to 0.1 mm on a graduated scale. A tube *b*, which may be slid back far enough to give access to the collimating lens, shields it from extraneous light. C is a steel box, impervious to light, containing the prisms. It is rigidly connected with the ring B. The prisms are held between brass plates which are screwed to the box after they have been adjusted to the minimum of deviation for $H\gamma$. Rigidly attached to the other end of the box is a brass tube *d*, in which the camera lens may be moved by a fine screw with divided head through a range of about 10 mm. The camera, D, of thin sheet steel, is attached to a flange at the end of the tube *d*, by screws which permit the camera to be adjusted to the axis of its objective. The outer end of the camera is rigidly joined to the base plate AA by two steel trusses. Thus the whole instrument is as a single piece, and when the "permanent" adjustments have been made (experience showed that they needed to be controlled [illegible] parts [illegible] the [illegible] desirable [illegible] are provided [illegible] are [illegible] H [illegible] 15 mm [illegible] plate holder [illegible] a small [illegible] to [illegible] portion of [illegible] the exposure [illegible] through which [illegible] light from the Geissler tube [illegible] The rays which are [illegible] thus utilized [illegible] necessary for the purpose [illegible] exclude [illegible] one of its [illegible]

[illegible] In a [illegible] length [illegible] one [illegible] which is very [illegible] the star [illegible] this [illegible] directed [illegible] possible to [illegible]

[illegible] material [illegible] spect [illegible] position [illegible] the spectrum [illegible] H [illegible]

[illegible] constructed by [illegible] Munich [illegible] spectrum [illegible] driving clock is [illegible] intervals [illegible] in K. A [illegible]

PLATE XV.



The Potsdam Spectrograph.

The careful attention of the observer is required during the exposure. Owing to changes of refraction etc., the declination slow-motion also needs to be occasionally turned. By turning either slow motion in the wrong direction, the star might be lost from the slit and the plate perhaps be spoiled.

Still it is in practice not necessary that the observer view star and slit continuously through the telescope F; if the driving clock is in good order, he will need to look in only at intervals of two or three minutes to see if adjustment in either co-ordinate is required.

A breadth of spectrum of about 0.3 mm was found most suitable for subsequent measurement under the microscope micrometer.

A cylindric lens was wholly dispensed with,—not being employed either in photographing, measuring, or enlarging the spectra.

The arrangement for producing comparison spectra is of great importance in an instrument designed for obtaining displacements of the spectral lines.

Very thin Geissler tubes containing hydrogen were used in nearly all cases

The tube is placed in the cone of rays from the object-glass, at right-angles both to the optical axis and to the slit, at a distance of 40 cm from the latter. The light falling upon the slit may be therefore considered as diffused and the slit as a source; hence the rays of Hγ will emerge parallel from the collimator.

It is very important that the slit should be fully and uniformly illuminated by the tube.

This is readily secured by this plan, and the loss of star-light due to the intervention of the tube amounts to but 17 per cent. Even if the tube should lack several degrees of being at right-angles to the slit, the latter will be still fully illuminated, so that a very careful adjustment in this respect is not necessary.

In the method employed by some observers of reflecting the comparison light in at the side, the tube being set parallel to the slit, there is great danger that the comparison rays will not be precisely symmetrical with the axis of the collimator, and a slight error in this respect may result in a spurious displacement greater than the actual effect of the motion of the star in the line of sight.

It may not be without interest to describe the mode of making the adjustments which I have for convenience called "permanent."

The adjustment of the collimator so that it shall lie in the optical axis of the refractor is effected by placing over the collimator-objective a collar carrying a disk of ground glass upon which concentric circles have been etched.

The object-glass of the telescope, having been stopped down to a small aperture, is directed towards the center of the Sun's disk. The diaphragm in front of the slit is turned so that the circular aperture (about 1 mm in diameter) falls at the center of the slit. A bright circular spot will then be formed on the ground glass, and the adjusting screws may be turned until it is concentric with the circle most nearly of its own diameter.

This adjustment, which could be so readily controlled, was found to require alteration but once during a period of three years.

The slit was adjusted in the focal plane of the collimating lens by viewing bright stars through a powerful eye-piece containing blue glass, and then moving the slit and eye-piece back and forth until the edges of the slit and the star images were equally sharp.

This adjustment having been once accomplished at a medium temperature, the slit was rigidly and permanently fastened to the collimator tube, subsequent variations of temperature being compensated for by the adjustment of the camera-objective.

The slit is set parallel with the equator by allowing a star to run along its edge, while the observer views it through the telescope F, the Geissler tube having been set in action to illuminate it. The width of the slit was generally kept constant at 0.02 mm during the investigations made with this instrument. It should be mentioned that during the progress of the spectrographic researches at Potsdam, the spectrograph was only rarely removed from the equatorial.

The adjustments which are necessary for each observation are required by the changes of temperature, which affect chiefly the optical parts of the instrument, the consequences of the expansion of the brass or steel portions being relatively slight. The adjustment of the slit in the focal plane for Hγ of the object-glass of the refractor is an important one. A series of photographs of the spectrum of a bright star is made (with driving clock running correctly, so that the breadth is as small as possible) at different settings of the collimator, and that setting is adopted at which the "node"* of the spectrum falls at the Hγ

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* Professor Keeler has aptly described the appearance of such a linear spectrum, obtained with a refractor corrected for the visual rays, as that of a vibrating rod (or string), with its (two) nodes and loops.

line. This process is repeated at various temperatures so that finally a table is made giving the proper setting of the collimator for the argument temperature.

It is desirable that this temperature should be read not only at the spectrograph but also near the object-glass of the refractor.

The adjustment of the photographic film in the focal plane of the camera-objective is effected, as already stated, solely by moving the lens itself. A series of photographs of the solar spectrum at slightly different settings will show what setting is the proper one at the given temperature, and here too a table is constructed giving the proper reading of the head of the screw for various temperatures. Neglect of these two adjustments will result in indistinctness of the spectra, and indeed sometimes in a spurious doubling of the lines.

The effect of different temperatures upon the resulting spectra is somewhat complicated, and mention should perhaps be made of the method of compensating for it in the subsequent micrometric measurement of the negatives. The change in the size of the image on the plate, due to the altered focal length of the camera objective, will be uniformly distributed over the whole image. Not so, however, the effect of the altered dispersion of the prisms; hence the combined result is that two spectra even of the same object taken at considerably different temperatures are neither identical nor geometrically similar. The best procedure is to reduce all the measurements to one single position of the camera lens for a standard temperature at which a good negative of the solar spectrum has been obtained. A curve or table for transforming the micrometer distances into wave-lengths is made from measures of a selected series of standard lines on the solar negative. The solar negative is then laid, film down, upon that of the star so that the lines of one spectrum shall form approximately the continuation of those of the others, thus furnishing a means of identifying those of the standard lines which are present in the star. All the lines of the stellar negative, or of a portion of it, are then carefully measured, the standard ones being specially designated. The reduction to the standard solar negative is now obtained for different portions of the spectrum, say for the two ends and the middle, by comparing the measured distances between identical lines in the stellar and solar spectra. If the standard lines were selected sufficiently close together, this correction will be so small that it may be without further reduction simply added to the tabular quantities which serve in interpolating the wave-lengths of the unknown lines lying between the standard ones. If the star belongs to a spectral type in which very few lines can be identified with standard lines of the solar negatives, the reduction is more difficult, and where greater accuracy is required a comparison spectrum of iron or cadmium should be photographed with the star.

When brilliant spark spectra are employed a small portion of the middle of the slit should be covered (by using the proper aperture in the diaphragm) during the short interval necessary to secure the impression of the comparison spectrum in order that the artificial lines may not hide the finer lines of the star.

According to the experience at Potsdam it is not desirable to prolong the exposure for spectra which are to be used for measures of displacement much over an hour or an hour and a half. In longer exposures elements of uncertainty will be introduced due to changes of temperature, of refraction, and of the instrument's position (however stable it may be).

An exposure of one hour was generally employed, and the faintest star included in the catalogue of motions of 51 stars in the line of sight is of magnitude 2.5.

Another spectrograph, similar to the one above described, has been more recently added to the equipment at Potsdam. It has but one prism and the dispersion is something like one-third of that of the other. This permits fainter objects to be observed (the writer has secured with it spectra of stars of the fifth magnitude), but on the other hand it makes the linear displacement correspondingly less so that the accuracy of measurements of velocities is necessarily much diminished.

A spectrograph very similar to the one first described has been constructed by Töpfer for the Pulkowa Observatory, where it is applied to the great refractor, and in the able hands of M. Belopolsky it may be expected to be of efficient service.

DARTMOUTH COLLEGE,
Hanover, N. H., Dec. 22, 1892.

ON THE USE OF THE CONCAVE GRATING FOR THE STUDY OF STELLAR SPECTRA.*

HENRY CREW.

During the summer of 1892 I had the opportunity of using a deep concave grating with the 12-inch and 36-inch refractors of the Lick Observatory. While handicapped in some directions this

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* Communicated by the author.

combination of grating and large refractor offers such manifest advantages in others, that I here give some of my meager experience with it in the hope that some one who has such a grating may find in the method all that it apparently promises.

The grating* employed had a radius of 22 inches and was ruled with 2886 lines to the inch.

The mounting was a wooden one designed and made on the spot, the same in principle as that of Professor Rowland, except that for the carriages which take the grating and eye-piece respectively, were substituted slides, which could be fixed at any point of the "beam" with screw clamps. The wooden frame of the instrument was covered with black cloth, and the whole, thus constituting a camera, was mounted, upon two heavy rods, on the eye end of the equatorial, in such a manner that it could slide up and down along the optical axis of the telescope.

A neat plate holder which Mr. Burnham made from a cigar box and the lid of a blacking box completed the outfit.

The adjustments were as follows:

(1.) Collimation was obtained by making the image of the object glass central on the ruled space of the grating.

(2.) Center of curvature, parallelism of slit and rulings, and the other grating adjustments made as usual with sunlight.

(3.) The slit in the photograph was placed in the photographic focus of the refractor by the following method which was suggested to me by Mr. Barnard: a very small plate-holder was made to fit easily over the slit plate. This holder carried a narrow strip of a "*Seed 26*" plate.

In various positions of the spectroscope along the optical axis the plate was exposed to a suitable star (β Cygni is an excellent one) for a second at a time, the photographic plate being slightly displaced across the slit between each exposure.

By an examination of the series of photographs thus obtained one can pick out the focus of maximum sensibility.

The instrument being adjusted the most difficult part remained, viz., to follow the star accurately. For this purpose I found the following method convenient.

One side of the camera was hinged so that it would open and shut after the manner of a bellows.

A hole, cut in this swinging part, enabled one to observe through it (whatever order of spectrum might be used), the direct reflection from the slit.

But when the slit is in the so-called actinic focus, it is at some

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* Mr. Brashear very kindly presented this grating to the Lick Obsesvatory.

distance from the apex of any cone of visible rays. This apex is, of course, the visual focus. The slit is, therefore, covered by a portion of the concave wave-surface of the visual rays and we have all the conditions necessary for diffraction through a single opening. The diffraction bands thus produced are *reflected* from the surface of the grating and are easily seen by the naked eye.

Not only so but they are very sensitive to any motion of the star across the slit-plate. One sees immediately whether the star is moving up and down the slit or across it. At the same time, one detects the *sense* of the displacement and corrects it with the slow motions.

The breadth of the central bright band, or the distance between its next door neighbors, serves to determine the width of the slit.

The ruled rectangle on the grating makes a neat background on which a small amount of asymmetry in the distribution of diffraction bands is made evident.

With this arrangement and this mode of following, a number of very fair photographs were obtained.

For instance, two or three of α Cygni and one of Arcturus showing twenty or more lines between *w. l.* 4100 and *w. l.* 4600.

With stars of the *First Type*, and third order of the grating, one gets uniformly the hydrogen lines F, $H\gamma$, h and H all on one plate, but the extremities are not in good focus.

The image of the spectrum band on the negative has about the same shape as a longitudinal section of a marlin spike, owing to the steepness of the color curve.

I was disappointed in not reducing the time of exposure to less than forty minutes, even with the thirty-six-inch glass. "Seed 26" plates were used.

This may have been due to bad focus at the slit, possibly to temperature changes in the tube. No adjustment was considered satisfactory that did not show at least 5 lines between H and K in the solar spectrum. The separation of H and K in the fourth order was $\frac{1}{30}$ of an inch.

At any rate, I never succeeded in getting any proportionality between the intensity of the negative and the time of exposure.

All told, I had but a few nights at my disposal and never found the source of the trouble.

Among the valuable features of the concave grating for this purpose is its astigmatism. These spectra measure from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch in width, so that one can never mistake an ordinary defect in the negative for a line.

Another advantage is that these spectra are normal, being superior in this respect to both prism and plane grating. This fact may prove useful in the identification of lines in the ultra-violet.

Thirdly, the amount of light lost by reflection and absorption in the lenses of the ordinary spectrometer may be a very uncertain and variable quantity. But whatever it be, it is certainly all saved in the use of the concave grating.

On the other hand, one labors under the great disadvantage incident to all gratings of not being able to use but a small fraction of the light which actually passes through the slit.

The method is, therefore, for the present at least, limited to the brighter stars, except possibly some of the Wolf-Rayet type which, while faint to the eye, may have their light so concentrated in various parts of the spectrum as to be quite within the reach of the grating. It is almost needless to add that such a grating deserves a good mounting in metal and should be used on a refractor corrected for the photographic rays, or better still, on a reflector.

Indeed, it appears that that the astronomical world is only just beginning to realize its indebtedness to Rowland for this instrument at once so beautiful and powerful.

NORTHWESTERN UNIVERSITY,
Evanston, Ill., Jan. 7, 1893.

THE HYDROGEN LINE H_β IN THE SPECTRUM OF NOVA AURIGÆ AND IN THE SPECTRUM OF VACUUM TUBES.*

VICTOR SCHUMANN.

The Hydrogen line H_β, as is well known, appears double in the spectrum of Nova Aurigæ, and, at times, these components are divided into still others. The cause of this division of H_β is at present a mystery. The hypothesis that in the spectrum of the Nova one has to deal with the light of a double star appears insufficient to explain all the variations which H_β, in this case, has shown. It is clear, however, from the paper of Dr. and Mrs. Huggins, that if one makes this supposition the basis of all his reasoning, he will have to assume, for the explanation of the case where H_β is not one dark line but three, (observation of Miss Maury, of Cambridge, U. S. A.), not simply one double star but a system of six bodies. Such a hazardous supposition, whatever the interaction of the six bodies, could scarcely be seriously considered in the interpretation of the spectrum of the Nova.

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* Communicated by the author.

The fact that the assumption of two stars moving in the line of sight has proved itself insufficient to explain the original appearance, and still less the later developments, of H_β in this spectrum, starts the question as to whether the hydrogen spectrum from terrestrial sources of light may not furnish a more satisfactory explanation. The question becomes more important in consideration of the fact that one can scarcely pass judgment upon stellar processes as revealed by the spectroscope with that certainty with which he interprets spectroscopic observations in the laboratory. Once assumed that it is possible to simulate with all its anomalies, or even with some of them, the spectrum of the Nova in the laboratory, the supposition of several bodies is no longer necessary; and the simpler explanation of new stars given by Zöllner in 1865* demands our consideration.

The literature of the hydrogen spectrum produced by artificial sources offers us little material for the interpretation of the case in hand. We have indeed some remarkably good measurements of wave-lengths in the hydrogen spectrum, but what is known of the behavior of hydrogen under various conditions of pressure and temperature is, in quantity, meagre, and in quality far below the standard reached by modern apparatus in other departments of spectroscopy.

Most of the observations in this field are of an old date and faulty, at least, on account of the inferior instrumental equipment of that time. What most interests the physical astronomer in the interpretation of stellar spectra, (in so far at least as they depend upon cosmical processes), are the changes of the spectrum produced by changes of pressure and temperature at the luminous source. The position of any line in the spectrum and its wave-length are matters of secondary importance.

During a series of years which I have devoted to the spectrum of the hydrogen tube, this dearth of literature induced me to carefully preserve all the results of my observations which might in any way extend our knowledge of the metamorphosis of this spectrum. I now find on my hands considerable new material relating to the subject. In order to compare earlier and later results extending over a period of years I have used the photographic method; and I have spared no pains to make my instrumental equipment the best of its kind. I have put a special emphasis upon the definition of the photograph. This was the more necessary as small dispersion had to be retained while other and more severe conditions were to be fulfilled.

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* *Zollner*, Photometrische Untersuchungen, Leipzig, 1865.

A part of this work refers to the reversal of the hydrogen lines. Experimental work in this direction is beset with difficulties, always great, at times insurmountable. So that I am free to confess that the results of my study of reversals, though they have occupied much time, fall far short of my expectations. And this is why I have not hitherto published anything on this subject. Since, however, certain of these phenomena remind one very forcibly of the changes in the lines of the spectra of Nova Aurigæ, I have decided to describe these phenomena of reversal without waiting to further verify or extend the results already obtained.

I may perhaps indulge the hope that my communication will arouse some interest and incite further rsearch in this field.

I pass now to the description of the experiments mentioned above. The following account is based upon two large series of photographed spectra and upon my photographic diary which contains definite information concerning each spectrum. My experiments refer to the influence of pressure and temperature upon the spectrum of the hydrogen tube. Circumstances were so arranged that the pressure in the tube never exceeded 100 mm. of mercury. The increase of temperature in the electric spark was obtained by the successive introduction into the circuit of a Leyden jar and a spark gap.

The apparatus was put together as follows:

The *Geissler-pump* was connected with one of Kipp's hydrogen generators and with the vacuum-tube whose spectrum was to be photographed. Every part of the apparatus which came in contact with the hydrogen was made of glass with the exception of a quartz stopper to be mentioned later. All the connections, by careful grinding, were made air-tight. The air-pump was filled with mercury which was chemically pure, and the drying tube with phosphoric anhydride spread out upon glass wool.

The *hydrogen* was prepared from the purest obtainable zinc and sulphuric acid, such as are used in regular medical practice, and before being admitted to the drying tube was purified by being passed in series through caustic soda, silver sulphate, (silver nitrate is absolutely worthless for this purpose) and potassium hydrate in stick form. The drying tube consisted of two chambers shut off by stop cocks from the rest of the apparatus and from each other. The hydrogen, after remaining for considerable time (generally over night) in the first chamber, was passed into the second chamber made of two U tubes, and after a still longer delay here, was admitted to the Geissler tube. The drying substance of both chambers (phosphoric anhydride) was spread upon loose fibrous glass wool of purest quality, in such a manner as to expose a large surface. (The ordinary wool of commerce cannot be recommended for this purpose). In this manner hydrogen can be dried more thoroughly than in any other way. If one simply passes the gas over the drying substance several days will be required for it to reach its maximum dryness. Moist hydrogen always gives the spectrum of water vapor in addition to that of hydrogen, if not in the visible region, at least in the ultra-violet, being, as is well known, especially strong in the neighborhood of w. l., 3000. Angström's units. When, therefore, the visible spectrum is free from foreign lines, one cannot conclude that the contents of his tube are pure. Indeed many impurities make their appearance higher up in the spectrum than the most refrangible of the hydrogen lines. Among these impurities is water-vapor.

The *vacuum-tube* was arranged "end on," and, to secure perfect transparency for the ultra-violet rays, was closed at one end with a conical quartz stopper 3 cm. in length. The capillary part of the tube lay in the geometrical axis of the stopper. The ends of the quartz stopper were plane, parallel, and perpendicular to the axis of the cone. For three-fourths of its length the stopper was carefully ground and fitted to the neck of the tube. The outer half of the cone was given a thin coating of grease. By this method one had nothing to fear from decomposition products of the grease rendering the contents of the tube impure, because the inner part of the stopper remains free from tallow. In like manner the joints of the air-pump and the hydrogen generator were made air-tight. Some tubes so fitted with quartz stoppers cannot be heated by a flame placed underneath. But with the above arrangement one runs no risk of breaking the tube by heating provided he does not bring the flame too near, and in no case up to, the quartz stopper. The tubes were filled, in the usual manner, after each exposure. They were not, of course, sealed off in the flame, but during the whole experiment remained in connection with the air-pump.

The *spectrograph* consisted of a 60° compound prism made up of a right and a left handed quartz together with two plano-convex quartz lenses. The focal length of these lenses for the D line was 750 mm. The capillary portion of the vacuum-tube lay in the prolongation of the axis of the collimator. Between the tube and the collimator was placed a condensing lens made up of two crossed quartz cylinder lenses. This stretched the luminous point out into a line, concentrated the light in the opening of the slit, and above all aided in good definition in the spectrum. Further details concerning the photographic outfit are reserved for the future, since they are aside from the present purpose of this paper.

The *photographic plates* I prepared myself. Those on the market are unsuitable, not being sufficiently sensitive in the F region. All plates intended for use in the neighborhood of the F line demand a strong silver iodide emulsion. A good proportion is 100 parts of silver bromide to 5 parts of silver iodide. Though it is not to be forgotten that such emulsions are valuable only when the silver haloids (Ag Br and Ag I) are deposited at the same time in the gelatine solution. A mixture of prepared silver bromide gelatine and prepared silver iodide gelatine shows very different properties from the above-mentioned emulsion, and is useless for work in the region of the F line. The preparation of this emulsion is best made according to the "silberoxydammonmethode" of Dr. J. M. Eder of Vienna.

The electrical apparatus was composed of a Grove battery of six cells, a Ruhmkorff induction coil giving a 25 cm. spark, a Leyden jar with an outer coating of 500 $cm.^2$, and a spark-holder. In general the strength of the primary current was 15 ampèrès, the electromotive force being 9 volts.

The following results were taken from two series of photographs. The one includes negatives taken under a pressure of 1, 2, 3, 5, 7, 10, 14, 19, 25, 32, 40, 50, 65, 80, 100 mm. of mercury respectively; the other series was made under identical circumstances, except that the respective pressures were 1½, 5, 9, 16, 30, 40, 100 mm. of mercury. The tubes, however, in the two cases were different. The tubes in the first series had the ordinary diameter of Geissler tubes, but the bore of the tubes in the second series was much smaller, amounting to not more than 0.27 mm. For each pressure at least two negatives were made, one with a Leyden jar in circuit, the other with a Leyden jar and a spark gap. Besides these those of several pairs of negatives were taken with the Leyden jar left out of the circuit, but with the spark gap retained. The two series include 57 negatives. All the details of these photographs do not here concern us. I limit myself to the mention of those of their spectral peculiarities which bear upon the subject of this paper. The introduction of the Leyden jar into the circuit increases the photographic energy of the light from the tube, but only up to a certain pressure. As soon as the pressure has reached a few millimeters the photographic effect begins to diminish, the spectrum gradually loses its great wealth of lines, until, at a pressure of 32 mm. only the two lines *H_γ and *H_δ are left, and even these are exceedingly weak and thin. From there on the negatives gain in intensity with increasing pressure, but the linear character of the spectrum does not return. It consists now only of the lines H_β H_γ H_δ and of these the first is the last to make its appearance. At a pressure of 100 mm., H_ϵ is added. On all the negatives there is a continuous band beginning with H_γ and extending far into the ultra-violet. The photographs of these series taken under low pressures are unimportant for our purpose. I pass therefore directly to the spectra exhibited under pressures of 65, 80, and 100 mm. pressure. Under a pressure of 65 mm. the prominent lines are H_β and H_γ. In these negatives they are well defined, although the sharpness of their edges is injuriously affected by broad, hazy fringes of considerable intensity, which shade off into the background from both sides of the lines.

Under a pressure of 80 mm., H_β has lost much of its definition, and close to it on each side one observes two fine thin lines; the fringe is here present also, only it is wider than under a pressure of 65 mm. H_γ has lost its definition completely but has increased in breadth. The same is true only in a still higher degree of its fringe. Under 100 mm. pressure the more refrangible component of the pair of lines just mentioned as belonging to H_β has disappeared, and in its place has appeared H_β itself, broad, but very weak; near by on the lower side one observes a thin line twice as broad, perhaps, as the thin line of the previous photograph. The fringe of H_β has now spread itself out more toward the blue than towards the red, thus displacing the middle of it towards the blue. In like manner the pair above mentioned appears displaced somewhat towards the opposite side. H_γ remains only as a very weak line which gradually loses itself in the broad, hazy background in which it lies. H_δ possesses still less character than $H\gamma$, and H_ϵ, which here appears for the first time, is only a faint maximum in the intensity of the spectrum at this place. All the more refrangible hydrogen lines observed in the spectra of the white stars do not make their appearance in photographs made under a pressure greater than 32 mm. In their stead one finds only the continuous spectrum mentioned above.

From this summary it is evident that it is H_β only that shows reversal as well as displacement. In none of the other lines do I

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* The subscripts of these two letters are wanting in the author's manuscript. Judging from the next two or three sentences, these subscripts were intended to be γ and δ respectively, and I have accordingly supplied them.—*Translator.*

find any trace of such a change in their appearance. On account of the difficulty of photographing H_α I have devoted no attention to it, though from my earlier observations I found it to be more easily and conspicuously reversed than H.[*]

If beside the Leyden jar one introduces a spark gap into the circuit, the effect of the jar is so altered that the maximum of photographic intensity which previously made its appearance under a pressure of 32 mm, now appears under a pressure of 2 mm. In fact all the variations of the spectrum produced by the Leyden jar without any spark gap, and under increasing pressure, are now obtained under a pressure of approximately 30 mm less. The only marked deviation from this rule which I noticed was under a pressure of 65 mm, where, as well as under 80 mm, the spectrum shows two fine transparent lines on both sides of the uncommonly faint H_β. No displacement of H_β was here observable. This makes the displacement under 100 mm pressure all the more striking. H_β now appears, in contrast to previous negatives, only as a double line. The more refrangible of its components is very deep [*intensiv*], much widened, and notably displaced towards the blue. The other component, on the contrary, is thin, by no means so widened as the first mentioned line, and very slightly displaced towards the red. H_γ appears on this negative as scarcely more than a slight increase of intensity in the spectral band, which extends farther than usual into the ultra-violet, and overpowers the two very faint maxima of intensity which, when the tube is illuminated for only an instant, one observes in the positions of H_δ and H_ε respectively.

But my experiments with narrower discharge tubes have led to quite different results. In these tubes, as is well known, the temperature is higher than in those of the larger calibre, because the energy of the electric spark is distributed to a smaller number of molecules. To obtain the reversals mentioned above, it occurred to me that this very circumstance would furnish a convenient means of obtaining a high temperature in the vacuum-tube, and it appeared not unlikely that this would favor the reversal of the hydrogen lines. This hope, however, has not been realized, either in this case or in any other, in which I have had the same object in view. The cause of this lies probably in the properties which narrow capillary tubes exhibit when submitted to a powerful electric discharge. If one simply passes the induction spark through a hydrogen tube whose capillary part is

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[*] Here again the subscript is wanting in the author's manuscript. H_β is probably the line intended.—*Translator.*

quite fine, say a quarter of a millimeter, he obtains a very bright hydrogen spectrum. But so soon as a Leyden jar is introduced into the circuit, the brightness of the hydrogen lines diminishes in a very striking manner; and the capillary portion of the tube, which before shone with a red light, flashes out with an intensely bright white light, while at the same time the hydrogen spectrum is replaced by the spectrum of the vapor of glass furnished by the inner wall of the tube. This spectrum of glass contains a great many lines. If we employ a still higher electro-motive-force, as can easily be done by introducing into the circuit a spark-gap, the capillary portion of the tube then shines with a brilliant white light. From the evidence furnished by its spectrum this radiation is entirely from the vapor of glass. The hydrogen spectrum does not make its appearance, and the conduction of electricity is entirely carried on by the vaporized constituents of the glass, with the exception of sodium, which, like hydrogen, appears to take no part in the process. We may remark incidentally that the spectrum of the vapor of glass is one of magnificent colors and very sharp lines. As the discharge current becomes stronger the lines widen, and when the strength of the discharge is still further increased the spectrum becomes continuous, with its maximum of photographic energy in the ultra-violet.

Thus the narrower of my two tubes showed only a trace of reversal in any of the spectra photographed with it. Of course by a pressure of 100 mm. the spectrum as photographed was only a dense continuous band in which one recognized H_β and H_γ as faint lines, together with a number of lines which do not belong to the spectrum of hydrogen.

So far as reversals are concerned, the experiments with the narrow tube need not be mentioned here. Indeed, I have mentioned them merely to indicate what a tremendous influence an apparently secondary matter may exert upon the reversal of the hydrogen lines.

If it be asked whether the phenomena of reversal as observed in my hydrogen spectra furnish, in themselves, an explanation of the reversal of the lines in the spectrum of Nova Aurigæ, the answer must be decidedly in the negative. At the same time it is possible that a sufficient extension of the observations may lead to a more satisfactory explanation of stellar processes than is possible on any hypothesis hitherto proposed, for "the solitary basis of interpretation of stellar spectra is laboratory work."*

LEIPSIC, 17, December, 1892.

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* See this journal, volume for 1892, page 582.

ON THE PROBABILITY OF CHANCE COINCIDENCE OF SOLAR AND TERRESTRIAL PHENOMENA.*

GEORGE E. HALE.

In a paper communicated to the Paris Academy of Sciences in 1887† M. Marchand has compared the solar and magnetic observations made at the Lyons Observatory between May 1, 1885, and Oct. 15, 1886. He concludes that "each of these maxima (of a curve of magnetic intensity) sensibly coincides with the passage of a group of spots or a group of faculæ at its shortest distance from the center of the solar disc." He adds that "there seems to be no relation between the intensity of the perturbations and the diameter of the spots."

The coincidence pointed out is a striking one, and some have come to regard it as expressive of a general law. The purpose of this paper, however, is to inquire whether such coincidence may not be of a purely accidental nature. Dr. Veeder believes that perturbations of terrestrial magnetism are caused by disturbance at the Sun's eastern limb, and he finds spots or faculæ at the places indicated whenever auroras are observed. M. Tacchini, on the contrary, holds that the position of the disturbed region on the solar disc has nothing to do with its effect on terrestrial magnetism.

In the observations of M. Marchand "the faculæ were generally observed up to a considerable distance from the two limbs; it may be concluded that they must have persisted as far as the center, although observation was rarely extended to that point." At present it is an easy matter to photograph faculæ wherever they occur on the solar disc with the spectroheliograph of the Kenwood Observatory. In previous numbers of ASTRONOMY AND ASTRO-PHYSICS I have described the instrument and some of the photographs obtained with it. Suffice it here to say that the faculæ are shown on these photographs to be far more numerous than visual observation or photographs taken with instruments hitherto employed had led us to assume. The great spot zones in the northern and southern hemispheres of the Sun are occupied by large numbers of faculæ, which sometimes extend in almost unbroken belts entirely across the disc.

In the following table are given the results of an examination of 142 photographs of the Sun, obtained on as many different days between Jan. 25, and Dec. 3, 1892, at the Kenwood Observ-

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* Communicated by the author.

† *Comptes rendus*, t. civ, p. 133.

atory. In successive columns are recorded the number of the plate, the date, and the number of groups of faculæ on the central meridian of the Sun.

Plate No. D.	Date. 1892.		h	No. of Groups of Faculæ on Central Meridian.	Plate No. D.	Date. 1892.		h	No. of Groups of Faculæ on Central Meridian.
277	Jan.	25,	3.12	1	752	June	10,	1.29	1
313	Feb.	4,	4.32	1	764		11,	11.26	2
315		6,	10.26	1	776		13,	10.54	2
322		9,	10.02	1	782		14,	11.58	2
336		10,	2.31	1	784		15,	10.37	2
343		11,	11.15	1	791		16,	10.45	1
344		12,	11.37	2	801		17,	2.42	2
351		13,	10.42	2	809		20,	12.33	2
361		15,	11.53	2	818		22,	4.31	0
366		16,	12.14	2	823		24,	5.04	3
370		17,	10.33	1	827		25,	12.05	2
375	Mar.	2,	1.11	1	839	July	5,	12.07	1
378		3,	2.38	2	851		6,	12.04	1
379		8,	3.20	1	858		7,	12.23	1
381		10,	11.52	2	862		8,	10.15	1
383		11,	11.03	2	863		11,	10.08	4
391		12,	11.35	2	874		12,	11.42	1
393		14,	12.51	1	884		13,	12.04	2
395		15,	11.59	2	893		14,	10.23	1
402		21,	12.19	1	907		15,	11.51	1
404		23,	4.08	—	915		16,	10.44	2
410		24,	1.08	1	929		18,	11.07	2
413		27,	11.20	1	934		19,	10.54	1
414		28,	11.56	1	956		21,	11.30	1
416		31,	3.22	1	969		23,	4.01	2
421	Apr.	3,	11.29	1	974		25,	12.48	1
429		6,	10.45	3	987		26,	12.05	0
467		9,	3.34	2	1001		27,	11.26	1
481		10,	3.25	1	1012		28,	12.15	1
487		12,	1.24	2	1013		29,	3.45	—
496		15,	1.23	0	1025		30,	12.50	2
505		18,	2.25	1	1033	Aug.	2,	11.52	1
508		19,	10.36	1	1062		6,	12.15	2
519		21,	9.34	1	1073		11,	11.25	1
524		22,	12.50	2	1098		18,	2.20	1
539		23,	10.57	2	1102		19,	2.11	2
549		25,	3.12	1	1106		20,	10.48	2
555		26,	9.42	2	1115		26,	10.52	2
560		27,	1.32	1	1132		27,	12.04	2
573		29,	12.47	1	1135		29,	3.23	0
577	May	3,	4.41	2	1144		31,	12.37	2
586		4,	12.18	1	1154	Sept.	1,	12.42	2
591		6,	10.20	2	1163		2,	12.56	2
605		7,	10.52	0	1168		3,	11.55	1
613		12,	12.00	0	1177		5,	11.20	1
632		14,	2.45	1	1186		6,	12.26	2
645		16,	10.24	1	1196		8,	4.38	1
649		17,	12.47	1	1201		9,	12.21	2
653		18,	2.02	2	1219		16,	11.00	1
656		21,	10.35	2	1215		15,	3.35	3
687		23,	2.04	1	1227		17,	11.10	1
698		25,	11.09	0	1242		20,	4.08	1
717		26,	2.22	1	1246		22,	11.22	2
730		27,	1.35	1	1253		23,	12.08	2
736	June	4,	11.32	1	1260		24,	12.22	1
743		6,	12.48	1	1270		26,	1.32	1

Plate No. D.	Date. 1892. h	No. of Groups of Faculae on Central Meridian.	Plate No. D.	Date. 1892. h	No. of Groups of Faculae on Central Meridian.
1275	Sept. 27, 11.12	1	1423	Oct. 19, 12.55	1
1285	28, 11.44	0	1429	25, 10.09	1
1299	29, 1.02	1	1439	27, 2.48	1
1313	30, 2.40	1	1444	28, 10.14	2
1317	Oct. 3, 10.51	2	1456	29, 11.54	2
1329	4, 1.25	1	1467	Nov. 5, 12.48	1
1339	5, 11.44	1	1472	10, 11.21	1
1342	7, 10.40	1	1480	12, 9.45	1
1351	10, 10.44	1	1503	15, 12.49	1
1365	11, 10.18	1	1511	16, 10.23	1
1376	12, 10.00	1	1529	18, 12.16	2
1393	13, 2.50	2	1538	19, 1.10	1
1395	14, 12.14	2	1542	21, 11.45	1
1404	15, 1.02	1	1549	26, 2.41	1
1411	17, 12.57	1	1551	Dec. 3, 10.36	1

It will be seen that out of the total number of 142 plates 132 show one or more groups of faculæ on the central meridian, *i. e.*, at their shortest distances from the center of the solar disc. Of the remaining 10 plates 8 have no faculæ on the central meridian, and 2 are doubtful. If we class the doubtful plates with those showing no faculæ in the position indicated, we find a probability of 0.93 that at a given time there will be one or more groups of faculæ on the central meridian.[*] Moreover, as the number of groups of faculæ is independent of the heliocentric longitude of the Earth, it follows from the observations employed that the probability that at a given time one or more groups of faculæ will be on a given meridian of the Sun is 0.93. This value will naturally be smaller in periods of decreased solar activity, but coincidences noted in epochs like the present can hardly be regarded as of great importance. The very fact that both eastern limb and central meridian advocates can find coincidences sufficiently numerous for their purpose, is strong evidence that chance alone may be involved. A 27-day period in terrestrial magnetism, however, would seem to mean that the solar rotation is an important factor.

Lord Kelvin has recently shown the extreme difficulty of regarding terrestrial magnetic storms as due to the direct magnetic action of the Sun. Instead of discouraging further research the utterances of so distinguished an authority should lead to a more careful study of solar phenomena, and a fuller consideration of the electrical forces possibly at work in our central luminary.

Brooklyn, Jan. 11, 1892.

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[*] The mean number of groups on the central meridian per day may be taken as a rough measure of the solar activity. Averaged for months we find for February 1.4, March 1.3, April 1.4, May 1.1, June 1.6, July 1.3, August 1.5, September 1.4, October 1.3, November 1.1. There was thus a maximum in June, and after August a steady decline.

STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

An examination of the photographs of stellar spectra received on December 6, 1892, from the Peruvian station of the Harvard College Observatory, and taken under the direction of Professor W. H. Pickering, has led to the discovery of the following objects of interest. The five stars given in the following table have spectra of the fifth type, consisting mainly of bright lines. This adds two more to the group of stars of this class in the constellation Argo, and increases the known number of these objects in the entire sky from forty-five to fifty, all of which are near the central line of the Milky Way. None of these five stars are catalogue stars. Their approximate right ascensions and declinations for 1900 are given, followed by their galactic longitudes and galactic latitudes.

R. A. 1900		Decl. 1900		G. Long.		G. Lat.	
h	m	°	′	°	′	°	′
10	13.3	−57	24	251	14	−0	48
10	47.9	−61	46	257	5	−2	36
11	55.2	−54	33	263	29	+6	53
13	24.3	−61	34	275	15	−0	1
15	55.0	−62	28	290	34	−8	28

In addition to the objects in the above list, a star in Scorpius, whose approximate position for 1900 is in R. A. 16^h $56^m.8$ Dec. —36° 40′, was found to have the hydrogen lines bright in its photographic spectrum. As this is a property of many known variables of long period and has already led to the discovery of a number of new variables, chart plates containing the region of this star were at once examined and resulted in the confirmation of its variability. The plate on which the star was found was taken in August 1892. The exact date is not given since the record has not yet been received from Peru. The magnitudes < 12.9 12.4, < 11.4, < 11.4, 9.5. < 10.4, 11.3, 11.8, 11.3, 12.6, < 11.2, 10.5, 10.5, 10.4, 10.1, < 11.4, < 11.4, and 9.2 were derived from measures of photographs taken on June 3, June 21, July 9, July 13, 1889; March 25, May 9, June 14, June 21, June 23, Sept. 5, Sept. 6, 1890; May 18, May 18, May 20, May 20, 1891; May 17, May 17, and August, 1892, respectively. From an examination of spectrum plates taken at Cambridge B. D. + 9° 4369, R. A. 19^h $56^m.3$, Dec. + 9° 14′ (1900) magn. 8.7, is shown to have a spectrum of the fourth type.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 11, 1893.

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* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Ultra-Violet Hydrogen Spectrum.—In a recent letter, Professor W. H. Pickering writes, "In looking over the October number of ASTRONOMY AND ASTRO-PHYSICS, I see that in the article by M. Deslandres, he supposes that the five hydrogen lines he refers to are new. All of them are found in the stellar spectra, and have been known for some years. He will find four of them referred to in the Draper Catalogue, p. 6. Two more beyond the five he mentions were found here last year in the photographic spectrum of Canopus, which have been accordingly designated as o and π. These more refrangible lines are not found, as might be supposed, in the bluest stars, but in those that are much more yellow. Thus the last line of the hydrogen series in the Orion stars is ι (iota), and the same is true of Sirius, which, by the way, is not a particularly blue star. Canopus, which contains the most complete series of hydrogen lines so far known, is of the second type, but rather bluer than our Sun. M. Deslandres' paper is interesting as giving further proof that the temperature of the prominences is probably higher than that of the solar surface."

Photography of Sun-Spot Spectra.—The spectra of Sun-spots have recently been photographed in the less refrangible region by Father Sidgreaves at Stonyhurst, and in the blue, violet and ultra-violet by Professor Young and Professor Hale. In a recent letter, Father Sidgreaves says: "The remarks I should make upon these plates (in region D — *b*) are precisely those Professor Hale has made in ASTRO-PHYSICS upon the spectra in the more refrangible end: intensified absorption, but no clear evidence of widening." Doubt is thus thrown on the reality of the widening of lines as an objective phenomenon, but that it occurs in certain cases cannot be controverted. If the effect were a subjective one, we should expect to find all the lines of the solar spectrum more or less widened in spots, but in reality certain lines appear to be widened, while others cross the dark absorption band without apparent change. In any case the photographic method should certainly prove far superior to the visual in studies of spot-spectra.

In a discussion of Father Sidgreaves' photographs at the November meeting of the Royal Astronomical Society, Capt. Abney said that he had made many photographs of Sun-spots and their spectra, and had come to the conclusion that there is really no widening of the dark lines over spots. The appearance of widening in the photographs he considers simply due to the fact that the plate is there less exposed.

Since the above note was written we have learned from Professor Young that he has obtained photographs which clearly show widened lines in the green region of the spectrum.

Schumann's Photographs of the Ultra-Violet Spectrum.—We have recently received through the kindness of Herr Victor Schumann, of Leipsic, two of his original negatives of the extreme ultra-violet spectrum. They were taken with his vacuum-spectrograph, the optical parts of which consist of a 70° fluor-spar prism and two fluor-spar lenses of 120 mm. focal length. The sensitive plates were made by Herr Schumann after his own formula, which gives the only plates yet obtained which are sensitive to the region above λ 1852.

Plate No. 2832 (Oct. 15, 1891), was exposed for one minute to the spark taken between aluminium electrodes, placed at a distance of 1 mm. from the slit. The spectrograph was exhausted to a pressure of 1 mm. of mercury. Four groups of strong lines are shown above λ 1852, all of which were previously unknown.

Plate No. 2889 (Oct. 26, 1891) greatly extends our knowledge of the spectrum of hydrogen. The vacuum-tube was in open connection with the interior of the spectrograph, so that the same pressure (3 mm. of mercury) existed in both. The extremely narrow slit (0.010 mm.) made necessary an exposure of 48 minutes. A strong group of lines is shown at λ 1620, and beyond this a very large number of fainter lines.

The definition and sharpness of the lines in these photographs surpasses anything we have ever seen. In the microscope the plates are seen to be free from grain, while but little of the sharpness is lost under great magnification. After a visit to Herr Schumann's laboratory and a careful study of his apparatus and methods, we have come to regard him as without an equal in experimental spectroscopy.

A Criticism by M. Faye.—It will be remembered that at the last summer's meeting of the British Association, Professor Schuster propounded in his Presidential Address before Section A, a number of suggestive questions in regard to the nature of the Sun and its spots. In *Comptes rendus*, Dec. 5, 1892, M. Faye recalls these remarks, and criticises them in the light of his well-known theory of the Sun.

M. Faye admits, as he has had occasion to do in consideration of the facts many times before, that the penumbra of a spot but very rarely shows any indication of cyclonic motion. But he adds that this by no means proves "that the gases enclosed in the umbra do not rotate, for the penumbra is a phenomenon wholly exterior to the spot; it can only exceptionally be affected by the gyration."

M. Faye's idea of the plan and section of a normal Sun-spot is given in a figure accompanying his paper. The cyclone is supposed to penetrate vertically through the lower strata of the photosphere, at the same time producing a considerable fall of temperature in its immediate vicinity. The small luminous clouds, formed at the extremity of ascending columns of vapor, and constituting the photosphere, exist at a lower level in the cooler region surrounding the spot, and are drawn out into the familiar filaments of the penumbra. The comparatively cool mass of gas through which we see the penumbra causes the decreased brilliancy by its absorption.

Thus the penumbra exists at a lower level and surrounds the cyclone at a distance. It therefore does not, in general, participate in its rotatory motion.

In support of his views, M. Faye presents an analogy drawn from a study of terrestrial cyclones. Meteorologists can hardly be said to accept unanimously M. Faye's theories of the latter phenomena, but in carrying out the parallel, the immobility of the cooled mass of air surrounding a cyclone is accounted for by the same reasoning employed in the case of spot-penumbræ.

In regard to Professor Schuster's suggestion that, as cyclones in a group should move around each other in a definite way, we ought to obtain decisive evidence for or against the cyclone theory by a close study of the relative positions of a group of spots, M. Faye admits the difficulty of accounting for the various appearances of a large spot in process of disintegration. He maintains, however, that there is always a tendency in the various parts toward circular motion, and again seeks support in terrestrial analogies.

Professor Schuster's somewhat cautious proposal that the spots be regarded as regions of the solar surface cooled by artificial evaporation due to electric discharges setting out from within the photosphere is not acceptable to M. Faye, on account of the difficulty of believing that a discharge could persist in the same place for months in a mobile and fluctuating medium.

M. Faye considers it possible that the violent movements at the surface of the Sun may cause slight disturbances of terrestrial magnetism, but sees no reason to modify our ideas on the purely mechanical origin of spots, pores and prominences or their periodicity.

Remodeling the Paris Reflector for Spectroscopic Work.—In No. 20, T. CXV, o the *Comptes rendus*, M. Deslandres describes the changes which he has made in the four-foot reflector of the Paris Observatory in order to adapt it to stellar spectrum photography, with special reference to the determination of motions in the the line of sight. The diagonal reflector of the Newtonian mounting has been removed, and a spectroscope is supported inside the tube of the telescope, with the collimator in the axis of the tube, and the slit in the focal plane of the great mirror. Three prisms of heavy flint glass give the necessary dispersion. Their dimensions, and those of the collimator, are not stated, but the linear scale of the photographs is such that in the blue part of the spectrum a displacement of one two-hundredth of a millimeter corresponds to a motion of 3.6 kilometres in the line of sight. According to these figures, one millimeter on the photographic plate is about equal to 11.7 tenth-metres at F, so that the scale is considerably larger than that of the Potsdam photographs, (1 mm = 13.0 tenth-metres at $H\gamma$). The spectrograph is enclosed in a box of sheet steel, in order to ensure the perfect rigidity of all the parts.

In order to keep the image of a star on the slit during long exposures, the polished steel slit-plate is slightly inclined, and light reflected from it is received in a four-inch telescope with diagonal eye-piece, placed near the lower end of the great tube within easy reach of the slow motions in right ascension and declination.

This arrangement of a spectroscope directly in the axis of a reflecting telescope is rendered possible by the great size of the mirror which M. Deslandres has at his disposal. It is evidently a very efficient one, and we may expect the Paris reflector to take a more prominent part in future astronomical work than it has occupied in the past.

According to M. Deslandres, exposures of two hours can be made with this apparatus without detriment to the definition. This brings fourth magnitude stars within the range of the instrument. Seventy measureable photographs of stellar spectra were obtained during the first ten months of the present year.

The advantages of these photographs, as compared with those obtained at Potsdam, are stated to be the following:

"(1). The emergent beams from the star and from the source of comparison are as nearly as possible of the same diameter, a condition which is necessary in absolute measurements of displacements, but which is not realized at Potsdam.

"(2). The displacement of the spectra is measured, not by the single ray $H\gamma$, as at Potsdam, but by all the lines of hydrogen, calcium, and iron, which are for the most part fine and sharp in the star and in the comparison source, and which are equally valuable for comparison, since they are united by the telescope in the same focus. The precision of the measurement is, therefore, augmented in a large degree.

"(3). The great surface of the mirror, although it makes the operation more difficult, permits the measurement of the motions of at least 250 of the stars in our sky, while the Potsdam apparatus gives only 60. The stars which surround the constellation Hercules and the region of the sky opposite to it are relatively numerous. They will give, with the telescope, the velocity of translation of the solar system in space, which velocity has not yet been determined."

The Spectrum of β Lyræ.—Herr Belopolsky gives in *A. N.* 3129 the results of some recent photographs of the spectrum of β Lyræ with the new spectrograph of the Pulkowa Observatory. The spectrograph is a duplicate of the one at Potsdam, but it has the advantage of the far greater light-gathering power of the 30-inch refractor. Herr Belopolsky's results confirm those of Pickering, who described in *A. N.* 3051 the main features of the peculiar spectrum of this star: but while Pickering's photographs extend from the upper limit of the violet to only a little below F, and did not admit of absolute measures of wave-lengths, Belopolsky's were made on orthochromatic plates, and extended so far down in the spectrum as to include the D_3 line. They, moreover, allowed the positions of the lines to be determined with accuracy. A translation of Herr Belopolsky's article will be given in our next number.

Recent Observations of Nova Aurigæ.—The new star in Auriga continues to attract a great deal of interest in astronomical centers. A perceptible increase of brightness took place in December, probably in the nebular lines, and certainly in the lower part of its spectrum, as the photographic brightness is now considerably less than the visual. Some doubt has been expressed in Europe as to the reality of the nebulous appearance of the star first reported at the Lick Observatory. Mr. Newall, who was unable to see the nebulosity with the 25-inch refractor at Cambridge, points out that if a star emits D and F light only, its image in the Lick telescope would consist of two stellar points situated on the axis at some distance apart, and that if the eyepiece should be focussed on one of these points, that image would be surrounded by a diluted disc some $7''$ in diameter, due to light diverging from the other point. With light of wave-lengths 500 and 575, the false nebulosity produced by chromatic aberration would be $4''$ in diameter. While this reasoning is entirely correct, we do not think it probable that the experienced observers on Mt. Hamilton have been deceived by the appearances above referred to. A few experiments with the focussing screw would quickly show whether the nebulosity was real, or merely an effect of chromatic aberration. That such experiments have been made, is evident from Mr. Campbell's article in *A. N.* 3133. Among the interesting points thus brought out, and explained from a consideration of the color curve of the 36-inch refractor, is the fact that a small nebula like Nova Aurigæ will, in general, appear relatively brighter in a small telescope than in a large one. In *A. N.* 3118, Mr. Barnard describes "a faint glow, perhaps half a minute in diameter," which could hardly have been produced by chromatic aberration.

Herr Renz, of Pulkowa, also describes the nebulous aspect of the Nova. Mr. Newall suggests that observations should be made with a large reflector, but up to the present, no such observations appear to have been published. We believe, however, that Mr. Roberts could find no evidence of nebulosity on photographs taken with his reflector.

The region of Nova Aurigæ was photographed on Sept. 25 and 30 by Herr Max Wolf. The nebulosity surrounding the star did not appear on the plates, as the spreading of the photographic image extended beyond the limits of the nebula, but a number of new diffuse nebulæ were discovered in the vicinity of the star, and there even appeared to be traces of nebulous appendages proceeding from the star itself. Unfortunately the weather did not permit sufficiently long exposures to remove all doubt as to their reality.

Mr. Campbell gives an account of his recent spectroscopic observations, and a drawing of the spectrum of the Nova, in *A. N.* 3133. The drawing is the same as that on page 717 of our October number, with the addition of a few faint lines in the violet. Nearly all the lines in the spectrum of the Nova were found either in the planetary nebula Σ 6, (G. C. 4390), or in the great nebula of Orion, and they are represented in many planetary nebulæ that were examined, although with some remarkable differences in the relative intensities of the lines. The wave-length of the chief nebular line in the spectrum of the Nova still continues to increase.

The observations of Herr E. Von Gothard (*A. N.* 3122 and 3129, and the January number of this journal), show the almost complete identity of the spectra of the Nova and the planetary nebulæ, in a very beautiful manner. The novelty of the apparatus with which the photographs were taken is not the least interesting feature of the observations. An object-glass prism of small refracting angle was placed over the end of a 10¼-inch reflector, and the spectra were photographed with an ordinary star camera. As we have already printed a full account of these observations, a further description is unnecessary. Herr Von Gothard's photographs, like those of Mr. Campbell, show that the Nova has a disc of sensible diameter, thus proving the existence of nebulosity around the central star, as described by the Mt. Hamilton and Pulkowa observers. Herr Von Gothard's apparatus was not well adapted to the determination of wave-lengths; hence, no doubt, his mistaken identification of the lowest line in the spectrum of the Nova in the yellow, with a line of the Wolf-Rayet stars at λ 582. According to Mr. Campbell, whose apparatus was capable of giving accurate positions, the line falls about midway between the bright lines in the Wolf-Rayet stars near λ 5814 and λ 5691, and it does not appear in any other spectrum so far examined.

It seems remarkable that no traces of the second nebular line at λ 4958 or of the third line at F appear upon Herr von Gothard's photographs, considering the distinctness with which the chief line is represented in the drawings made from them. The peculiar character of the curve of sensitiveness of an orthochromatic plate may account for the absence of these lines, or it may be that the drawing is not intended to represent relative intensities with any approach to accuracy.

Some of Herr von Gothard's conclusions are not new, but of those that are, one of the most interesting is that the line at λ 3727 is very much brighter in large diffuse nebulæ than in small nebulæ of the planetary type, and the brightness of this line in a great number of different nebulæ would be worthy of investigation. It will be remembered that it was this same line which surprised Dr. Huggins by appearing on some of his photographs of the spectrum of the Orion nebula and being absent from others taken with a slightly different position of the slit. The line was strongest, however, in parts of the nebulæ near the stars of the trapezium, and therefore in regions which were presumably most condensed.

A very complete investigation of the spectrum of Nova Aurigæ with the Pulkowa spectrograph, during the early months of 1892, has been published by Herr A. Belopolsky, in the *Bulletin de l'Academie Imperiale des Sciences de St. Petersbourg.* It deals entirely with the spectrum of the star before its reappearance in

August, and is one of the most valuable contributions to the history of the Nova which has appeared.

No. 26 of the Publications of the Astronomical Society of the Pacific contains, besides many other articles of great interest, an admirable review of the whole spectroscopic history of Nova Aurigæ by Professor Campbell. It is based on the observations made at Mt. Hamilton, and gives all the measurements of lines made before and after the reappearance of the star. A table of the chromosphere lines is given, with numbers proportional to the product of their frequency and intensity, and it is shown that nearly all the prominent lines in the winter spectrum of the star are prominent lines in the chromosphere spectrum, and *vice versa.*

The motion of the star in the line of sight since its reappearance, as deduced from the displacement of the chief nebular line, is exhibited in the following table a part of which was printed in our December number:

Date	λ	Velocity.	Date	λ	Velocity.
1892, Aug. 20	5003.6	– 128 miles	1892, Sept. 22	5002.5	– 169 miles
21	3.7	125	Oct. 12	3.6	128
22	3.7	125	19	3.8	121
23	3.1	147	Nov. 2	4.4	99
30	2.4	173	3	4.7	87
Sept. 3	2.4	173	9	4.4	99
4	1.9	192	16	4.9	80
6	2.1	184	17	4.9	80
7	1.9	192	24	4.5	– 95
15	2.2	– 180			

Disintegration of Holmes' Comet.—Photographs taken by M. Deslandres at Paris, with a small photographic lens of short focus, show that on the 21st of November Holmes' comet was beginning to divide into two parts. On the 10th of December an hour's exposure failed to bring out any trace of the comet. The doubling detected by M. Deslandres was no doubt part of the process of diffusion (and perhaps disintegration) which has been observed of late.

Astronomical Work at Harvard College Observatory in 1892.—The forty-seventh Annual Report of the Director shows that the great activity which has characterized the work of the Harvard College Observatory in the past has been fully maintained in 1892. A mere list of the different objects observed would extend beyond the limits of a note. Some of the more important astro-physical observations made either at Cambridge or at the branch Observatory at Arequipa, Peru, may, however, be mentioned as examples.

In Peru, Mr. Bailey finished the work of observing the southern stars with the meridian photometer. Professor Wm. H. Pickering, in charge of the station, observed the Moon and planets with the thirteen-inch equatorial. Many new double stars were also found. In connection with the Henry Draper memorial nearly two thousand photographs of stellar spectra were taken with the eight-inch Bache telescope, and their examination led to the discovery of many interesting objects. At Cambridge, 2777 photographs of stellar spectra were taken with the eight-inch Draper telescope, and 996 with the eleven-inch telescope. A large proportion of the latter were devoted to the spectra of β Aurigæ and ζ Ursæ Majoris, in order to determine the law of the periodic doubling of the lines. Many photographs of Nova Aurigæ and its spectrum were also made. We note with pleasure that sufficient money has been subscribed by friends of the Observatory to enable Professor Pickering to proceed with the construction of a fireproof building for storing these invaluable photographs.

The report begins with an acknowledgement of the indebtedness of the Observatory in the past to the mechanical skill of the late George B. Clark.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR MARCH.

H. C. WILSON.

Mercury will be "evening star" during March, and will be visible to the naked eye, an hour after sunset, during the two middle weeks of the month. The planet will be at greatest elongation east from the Sun, 18° 27′, March 14. After this date the planet will move rapidly westward, reaching inferior conjunction on the evening of the last day of the month.

Venus will be "morning star," but very close to the Sun.

Mars will be visible in the west in the early evening. Having passed by Jupiter this planet will have proceeded so far to the eastward that the Moon will overtake it two days later than Jupiter. The conjunction of Mars and the Moon will occur March 21, at 10^h 50^m P. M. central time.

Jupiter may be observed best in the twilight during March. After dark he will be to low in the west to be well seen. A conjunction of Jupiter and the Moon will occur March 20, at 2^h 37^m A. M. central time. In northern latitudes on the other side of the Earth an occultation of Jupiter will be seen.

Saturn comes to opposition March 29, and so is in excellent position for observation during the greater part of the night. For chart of his position in the sky see our January number, page 80. The rings may be well seen since they make an angle of 8° with the line of sight. There will be two conjunctions of Saturn with the Moon during this month, the *first* occurring March 4, at 5^h 36^m P. M. central time, with Saturn 1° 12′ north of the Moon; the second March 31, at 9^h 24^m P. M., Saturn 1° 5′ north of Moon.

Uranus is approaching opposition, and is in good position for observation after midnight. For place in the constellations see January No., p. 80. Uranus will be in conjunction with the Moon, 1° 35′ north, March 7, at 3^h 28^m A. M. central time.

Neptune will be in good position for observation during the first half of the night. For his position in Taurus see our December No., p. 937.

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
1893.	h m	° ′	h m	h m	h m
			MERCURY.		
Mar. 5	23 59.8	+ 0 12	7 01 A. M.	1 04.8 P. M.	7 09 P. M.
15	0 46.7	+ 7 35	6 39 "	1 12.2 "	7 46 "
25	0 52.7	+ 9 22	5 58 "	12 39.0 "	7 20 "
			VENUS.		
Mar. 5	22 12.8	− 12 23	6 03 A. M.	11 18.1 A. M.	4 33 P. M.
15	23 00.0	− 7 55	5 54 "	11 25.9 "	4 58 "
25	23 46.1	− 3 06	5 41 "	11 32.4 "	5 24 "
			MARS.		
Mar. 5	2 49.0	+ 17 05	8 40 A. M.	3 53.5 P. M.	11 07 P. M.
15	3 15.5	+ 19 00	8 18 "	3 40.6 "	11 03 "
25	3 42.5	+ 20 41	7 58 "	3 28.3 "	10 59 "
			JUPITER.		
Mar. 5	1 36.7	+ 8 57	8 02 A. M.	2 41.3 P. M.	9 20 P. M.
15	1 44.8	+ 9 45	7 28 "	2 10.2 "	8 53 "
25	1 53.5	+ 10 34	6 54 "	1 39.4 "	8 25 "
			SATURN.		
Mar. 5	12 45.4	− 1 59	7 53 P. M.	1 48.3 A. M.	7 44 A. M.
15	12 42.8	− 1 41	7 10 "	1 06.4 "	7 03 "
25	12 40.0	− 1 22	6 26 "	12 24.3 "	6 22 "

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			URANUS.		
Mar. 5	14 33.0	− 14 33	10 31 P. M.	3 35.6 A. M.	8 40 A. M.
15	14 32.1	− 14 29	9 51 "	2 55.4 "	8 00 "
25	14 31.0	− 14 23	9 10 "	2 15.0 "	7 20 "
			NEPTUNE.		
Mar. 5	4 28.4	+ 20 14	10 04 A. M.	5 32.7 P. M.	1 01 A. M.
15	4 28.9	+ 20 15	9 25 "	4 53.9 "	12 23 "
25	4 29.6	+ 20 18	8 54 "	4 23.0 "	11 55 P. M.
			THE SUN.		
Mar. 5	23 06.4	− 5 45	6 30 A. M.	12 11.5 P. M.	5 53 P. M.
15	23 43.0	− 1 50	6 11 "	12 08.8 "	6 06 "
25	0 19.6	+ 2 07	5 53 "	12 05.9 "	6 19 "

Configuration of Jupiter's Satellites at 8^h p. m. Central Time.

Mar.		Mar.		Mar.	
1	3 1 ○ 2 4	12	4 2 1 ○ 3	23	3 2 ○ 1 4
2	3 2 ○ 1 4	13	♃ 4 2 ○ 3	24	3 1 2 ○ 4
3	3 1 ○ 2 4	14	4 ○ 1 2 3	25	3 ○ 4 1 2
4	○ 3 1 2 4	15	4 1 3 ○ 2	26	♃ 4 1 ○ 3
5	2 ○ 3 4 ●	16	3 2 4 ○ 1	27	4 2 ○ 1 3
6	2 1 ○ 3 4	17	3 1 2 ○ ●	28	4 ○ 2 3 ●
7	○ 1 3 2 4	18	3 ○ 1 2 4	29	♃ 4 1 ○ 2
8	3 1 ○ 2 4	19	1 2 ○ 3 4	30	4 3 2 ○ 1
9	3 2 4 ○ 1	20	2 ○ 1 3 4	31	4 3 1 2 ○
10	4 3 1 ○ ●	21	○ 1 2 3 4		
11	4 3 ○ 1 2	22	1 3 ○ 2 4		

Phenomena of Jupiter's Satellites.

1893.	h m				h m		
Mar. 1	7 10 P. M.	II	Tr. In.	Mar. 19	6 02 P. M.	II	Sh. Eg.
3	5 38 "	II	Ec. Re.	20	6 26 "	I	Tr. In.
4	6 41 "	III	Ec. Dis.		7 06 "	I	Sh. In.
11	7 12 "	III	Oc. Dis.	21	6 35 "	I	Ec. Re.
12	7 15 "	I	Oc. Dis.	26	6 13 "	II	Sh. In.
13	6 38 "	I	Tr. Eg.	28	5 49 "	I	Oc. Dis.
	7 23 "	I	Sh. Eg.	29	6 35 "	III	Tr. In.
17	7 05 "	II	Oc. Dis.				

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
Mar. 14	B.A.C. 7550	6.3	16 42	48	17 39	281	0 57
21	65 Arietis	6.0	6 42	35	7 36	289	0 54
24	49 Aurigæ	5.7	7 39	51	8 33	324	0 54
25	υ Geminorum	4.3	6 25	47	7 15	335	0 50
26	υ^1 Cancri	5.7	4 44	89	5 59	298	1 15
28	42 Leonis	6.0	5 46	81	6 49	328	1 03

Phases and Aspects of the Moon.

	d	h m	
Full Moon	Mar. 2	10 03	A. M.
Apogee	" 8	6 06	P. M.
Last Quarter	" 10	11 14	A. M.
New Moon	" 17	10 34	P. M.
Perigee	" 20	1 06	"
First Quarter	" 24	3 33	"

Minima of Variable Stars of the Algol Type.

U CEPHEI.

R. A................$0^h\ 52^m\ 32^s$
Decl..................$+81°\ 17'$
Period............$2d\ 11^h 50^m$
1893.

Mar.	1	9 P. M.
	6	9 "
	11	9 "
	16	8 "
	21	8 "
	26	8 "
	31	7 "

ALGOL.

R. A................$3^h\ 01^m\ 01^s$
Decl..................$+40°\ 32'$
Period............$2d\ 20^h 49^m$

Mar.	9	10 P. M.
	12	6 "
	29	11 "

λ TAURI.

R. A................$3^h\ 54^m\ 35^s$
Decl..................$+\ 12°\ 11'$
Period............$3d\ 22^h 52^m$

Mar.	2	11 P. M.
	6	10 "
	10	9 "
	14	8 "
	18	7 "
	22	6 "

R. CANIS MAJORIS.

R. A..............$7^h\ 14^m\ 30^s$
Decl................$-\ 16°\ 11'$
Period............$1d\ 03^h 16^m$

Mar.	6	8 P. M.
	7	11 "
	14	7 "
	15	10 "
	23	9 "
	24	Midn.
	31	8 P. M.

S ANTLIÆ.

R. A................$9^h\ 27^m\ 30^s$
Decl.................$-28°\ 09'$
Period............. $7^h\ 47^m$

Mar.	1	2 A. M.
	2	1 "
	3	12 "
	3	12 P. M.
	4	11 "
	5	10 "
	6	6 A. M.
	6	10 P. M.
	7	5 A. M.
	7	9 P. M.
	8	5 A. M.
	9	4 "
	10	3 "
	11	3 "
	12	2 "
	13	1 "
	14	1 "
	15	12 "
	15	11 P. M.
	16	11 "
	17	10 "
	18	6 A. M.
	18	9 P. M.
	19	5 A. M.
	19	9 P. M.
	20	5 A. M.
	21	4 "
	22	3 "
	23	3 "
	24	2 "
	25	1 "
	26	1 "
	26	midn.
	27	11 P. M.
	28	11 "
	29	10 "
	30	6 A. M.

S ANTLIÆ CONT.

Mar.	30	9 P. M.
	31	5 A. M.

δ LIBRÆ.

R. A..............$14^h\ 55^m\ 06^s$
Decl...............$-\ 8°\ 05'$
Period..........$2d\ 7^h\ 51^m$

Mar.	3	4 A. M.
	10	3 "
	17	3 "
	24	3 "
	31	2 "

U CORONÆ.

R. A..............$15^h\ 13^m\ 43^s$
Decl...............$+\ 32°\ 03'$
Period...........$3d\ 10^h\ 51^m$

Mar.	3	3 A. M.
	10	1 "
	16	midn.
	23	8 P. M.
	30	6 "

U OPHIUCHI.

R. A.............$17^h\ 10^m\ 56^s$
Decl...............$+\ 1°\ 20'$
Period.......... $0d\ 20^h\ 8^m$

Mar.	2	5 A. M.
	3	1 "
	7	6 "
	8	2 "
	13	3 "
	18	4 "
	23	5 "
	24	1 "
	28	5 "
	29	1 "

COMET NOTES.

New Outburst of Light in Holmes' Comet.—During the past month Holmes' comet has been very faint. On Jan. 12 it was so faint that with a sixth magnitude star in the field of view the condensation about the nucleus could not be seen with the 16-inch refractor of Goodsell Observatory, although the faint nebulosity of the comet as a whole could just be discerned with the 5 inch finder. On Jan. 16, however, at 8 P. M. central time, we were astonished to find in the place of the nucleus, what looked like a bright planetary nebula of about the seventh magnitude. Finding no nebula put down for that place in Dreyer's catalogue, we tried a micrometer measure of R. A. from a 10 magnitude star about 1′ distant, and in a few minutes detected motion which agreed with that of Holmes' comet. The nucleus was at first very hazy but afterward became more starlike and about as bright as an 8 mag. star. The coma was not more than 30″ in diameter and very bright, almost as bright as when I first saw the comet on Nov. 11. The temperature was so low on that night (14° below zero F.) that we could not safely attempt to put the spectroscope on the telescope.

On Jan. 17, we received telegraphic announcement of the outburst, it having been observed by Palisa at Vienna Jan. 16. On Jan. 18, we again observed the comet and found it still bright. The nucleus was about 8.5 magnitude and more star-like than on the 16th. The coma was fainter than on the 16th but its diameter was more than doubled, >1′, and it was a little elongated in the direction 45°. We could trace also an exceedingly faint tail extending 5′ or more in the direction 45°. In the 5-inch finder the faint nebulosity of the November comet has almost wholly faded out of sight. It looks as if the new Holmes' comet were about to repeat the phenomena of the first, only on a smaller scale because farther away. How this will fit in with Mr. Corrigan's theory is not easy to see.

The ephemeris given below was computed from the elements by Professor Boss (*Astr. Jour.* No. 283) which up to the present time represent the course of the comet very closely. We do not give the column of "Brightness" for it is evidently useless to predict the brightness of such an extraordinary object.

Holmes' Comet.—Holmes' Comet has been observed for position at the Dearborn Observatory on every clear night since the 21st of November. About the middle of December it had become so faint as to be a difficult object for observation with the 18½-inch refractor.

In January the volume had greatly diminished, and the comet appeared as a faint nebula.

On the 14th of January it was observed as a faint, globular nebula about 2′ of arc in diameter.

On the 16th inst., however, instead of a faint diffused nebula, there was seen a beautiful nebulous star of the 8.5 magnitude. The central portion was star-like,. and the nebulosity surrounding it was about 10″ of arc in diameter. The remarkable transformation from an attenuated nebula to a nebulous star, therefore, must have taken place some time between the 14th and 16th inst. The comet was observed again on the 18th, when it presented nearly the same appearance as on the previous night, except that the nebulous envelope was somewhat larger. On the 19th the star-like nucleus had expanded to 3″.7, and the envelope was about 7″.6 in diameter.

If the comet would retain its stellar appearance it might be visible in all parts of the orbit as has already been pointed out by Schulhof. G. W. HOUGH.

Northwestern University, Jan. 19, 1893.

Remarkable Transformation of Holmes' Comet.—Holmes' comet had become exceedingly difficult to see and to measure in the 12-inch.

It had enlarged and diffused from its previously bright and well defined condition until at the last observation it was merely a great and feebly luminous mist on the face of the sky. There was a small and very faint condensation which could be seen and bisected only with the greatest care.

On the night of Jan. 16 after a spell of clouds and fog, the sky cleared about dark. At 6:30 I turned the 12-in. on the position of the comet in hope of getting at least one more measure of its position if it could be seen at all. To my astonishment I found in the place of the comet a small, bright, hazy, star-like body. I had used a low power (80) for the purpose of more readily finding the comet. I was familiar enough with this portion of the sky to know that no nebula like this existed there. Several pointings were made to be sure of the position. The place fell exactly where the comet ought to be. There was, however, a nebula close to this position (N.G.C.561) and it might be that object brightened up. To settle whether it was the comet, I began to take differences of right ascension between the object and a star. These soon established beyond doubt that the object really was Holmes' comet. With a magnifying power of 150 it was about ½′ in diameter, round and strongly condensed, but with no tail. Feeble traces of a nucleus could sometimes be made out. In the 3¼-inch finder the comet could not be distinguished from a star. It was perfectly stellar and of 7½ or 8 magnitude —comparisons were made with stars in field of view for its light and such will be kept up.

Careful measures were made of the comet's position with the micrometer.

At $8^h\ 10^m$ a setting of the wires gave the diameter = 29″.4 my estimate being 30″. While under observation the comet seemed to be perceptibly brightening. Two more observations for its diameter at $9^h\ 45^m$ gave 32″.4. At this time the nucleus had developed clearly and was very noticeable as a small, ill-defined star. I am sure the nucleus was actually developing while under observation.

At $10^h\ 0^m$ there was no longer any question but that the comet was getting brighter and the nucleus developing.

An opportunity now offering to observe the comet with the 36-in. I went to that instrument. With 520 diameters the comet was perfectly round and fairly well defined with a bright, hazy, star-like nucleus. The circular disc of light was greenish blue and the nucleus yellowish. The comet was indeed a perfect miniature of the appearance it presented with the 12-inch on Nov. 8th when I first saw it.

I now began a series of measures of the diameter with the micrometer of the 36-in. The definiteness of the outline of the comet may be inferred from the accordance of the following independent measures:

	h	m		″
Standard Pacific Time	10	29	diameter =	43 4
	10	30		44.9
	10	31		43.6
	10	42		47.8
	10	43		47.9
	10	45		46.0
	11	13		47.3
	11	15		46 1

Position angle of the wires during the measures = 70°.

The measures seem to show that the object was expanding while under observation.

This is certainly the most remarkable comet I have ever seen, taking every thing into consideration.

About 9 o'clock a dispatch came announcing that the outburst had also been observed at Vienna by Palisa. E. E. BARNARD.

Mt. Hamilton, 1893, Jan. 17.

POSTSCRIPT.—Holmes' comet was observed again with the 12-inch on the 17th of January. The principal change to record had occurred in the nucleus. This was now a bright, yellowish star. The coma by contrast or in reality, was fainter, and not distinctly terminated. The comet in appearance resembled a star shining through fog. Everything in this night's view was subordinate to the nucleus which shone out conspicuously. This nucleus was more conspicuous than an 8th magnitude star though it lacked the intensity of a stellar point. In the finder the comet appeared, as a whole, possibly a little brighter than on the 16th. It now looked like a small, bright, hazy star.

With 150 the nebulosity was so indefinitely terminated that only a rude guess of its diameter could be made. One setting of the wires gave diameter 46″.

There is no question but that I had actually watched the development of the nucleus on the 16th, or if it had existed previously, the unveiling of it had been observed.

When I first saw the comet on the 16th there were only the feeblest suspicions of a nucleus, the comet being very strongly condensed. By 9 o'clock, or a little before, a faint star-like nucleus had begun to show; from this time on it became clearer and brighter until the comet was too near the horizon to see. On the 17th the nucleus had eclipsed everything else.

The observations of the 17th were confined to the 12-inch.

Jan. 18.—The nucleus to-night has faded wonderfully. It is just distinguishable—about 13 mag. The comet is somewhat larger. There is a rather rapid brightening in the center in which the faint nucleus can occasionally be made out.

Mt. Hamilton, Jan. 18, 1893. E. E. BARNARD.

The Recent Phenomena of Holmes' Comet.—The remarkable phenomena which have been recently observed in Holmes' comet favor in a high degree, the hypothesis that this body is the result of a collison between two asteroids. The first effects of such a collision would be to expand the volume of the resultant body, some of the matter whereof would be thrown entirely beyond the sphere of attraction due to the mass of said body. This matter, thus diffusing in space, appeared as the rapidly expanding nebulous envelope seen shortly after the discovery of the comet. But, probably, the greater portion of the matter did not pass beyond the sphere of attraction, and if so it must have fallen back toward the centre of gravity of the mass. As expansion and separation of the matter diminished the brightness of the nucleus, so must the contraction above described have increased the brilliancy thereof, producing the effect recently observed.

Furthermore, the fall of this matter must have generated heat, and another vaporous envelope similar in many respects to that produced by the original collision. In fact, under this hypothesis, we should expect several such alterations in the light, and in the dimensions of the body. The heat generated by the fall of matter has also probably increased the brightness of the nucleus, and the spectroscope will probably throw much light on this point. Another phenomenon which would naturally result from such a collision, would be the rotation of the resultant mass; for unless the centres of inertia of the original asteroids, and the point of impact, were in the same straight line, a condition which is possible but quite improbable, axial rotation must have resulted and such rotation, it is very obvious, might produce variations in the light of the nucleus.

Furthermore, the rotation of such a mass of debris, as it were, would cause internal collisions which would result in heating and expanding the mass.

To one or all of these causes we may, I think, reasonably attribute the recent remarkable phenomena displayed by Holmes' comet.

St. Paul, Minn., Jan. 21, 1893. SEVERINUS J. CORRIGAN.

Holmes' Comet—Its Probable Relation to the Zone of Asteroids.—The mean distance of this body is 3.58—less than that of Thule or either of several asteroids on the outskirts of the zone; its period is 2480 days, also less than those of some minor planets; the inclination of its orbit to the plane of the ecliptic is 20°, less than that of many asteroids. The eccentricity is almost the same with that of Æthra, the 132d asteroid; the aphelion is within the orbit of Jupiter; the perihelion distance is 2.17, or less than those of several minor planets. It becomes, therefore, a question whether Holmes discovered a comet or a planet. The question as to its origin is one well worthy of consideration. If the groups of asteroids had separate common origins may not reunions or collisions be also possible? Such collisions, however, on account of the small masses and the relatively slow motions would not be violent.

The result of observation and discussion in this new field of research will be looked for with interest by all astronomers. DANIEL KIRKWOOD.

Ephemeris of Comet 1892 III (Holmes).

[Computed by H. C. Wilson and A. G. Sivaslian from Boss' Elements, *Astr. Jour.* 283].

Gr. Midn.	App. R. A.			App. Decl.			log r	log Δ
	h	m	s	°	′	″		
Feb. 2	1	45	43.6	+ 33	49	34	0.4332	0.4228
4	1	48	44.3	33	52	23		
6	1	51	47.2	33	55	28	0.4357	0.4431
8	1	54	52.4	33	58	50		
10	1	57	59.7	34	02	27	0.4382	0.4529
12	2	01	09.1	34	06	18		
14	2	04	20.5	34	10	22	0.4407	0.4529
16	2	07	33.8	34	14	39		
18	2	10	48.9	34	19	09	0.4432	0.4624
20	2	14	05.8	34	23	49		
22	2	17	24.4	34	28	38	0.4457	0.4717
24	2	20	44.6	34	33	36		
26	2	24	06.4	34	38	42	0.4482	0.4807
28	2	27	29.6	34	43	54		
Mar. 2	2	30	54.3	34	49	13	0.4507	0.4894
4	2	34	20.3	34	44	37		
6	2	37	47.5	35	00	05	0.4532	0.4979
8	2	41	16.0	35	08	38		
10	2	44	45.8	35	11	14	0.4556	0.5061
12	2	48	16.7	35	16	51		
14	2	51	48.9	35	22	30	0.4581	0.5141
16	2	55	22.1	35	28	11		
18	2	58	56.2	35	33	51	0.4605	0.5217
20	3	02	31.4	35	39	31		
22	3	06	07.6	35	45	11	0.4630	0.5301
24	3	09	44.7	35	50	48		
26	3	13	22.7	+ 35	56	21	0.4654	0.5363

New Elements of Comet 1892 III (Holmes).—M. Schulhof in *Astr. Nach.* 3140 gives the following elements of comet Holmes, derived from observations Nov. 9, 15, 21, 25, Dec. 9 and 13:

$$\text{Epoch} = 1892,\ \text{Dec. } 13.5,\ \text{Paris M. T.}$$

$$\left.\begin{aligned} M &= 26^\circ\ 08'\ 33''.8 \\ \pi &= 345\ \ 53\ \ 12\ .2 \\ \Omega &= 331\ \ 42\ \ 12\ .1 \\ i &= 20\ \ 47\ \ 22\ .9 \end{aligned}\right\}\ \text{Mean equinox 1892.0}$$

$$\varphi = 24\ \ 13\ \ 12\ .6$$

$$\mu = 513''.548$$

$$\log a = 0.559617$$

$$T = 1892\ \text{June } 13.2379\ \text{Paris M. T.}$$

$$\text{Period} = 6.909\ \text{years.}$$

These elements agree closely with those of Professor Boss (*Astr. Jour.* No. 283) and represent the observations very exactly. They are doubtless very near the true elements of the orbit.

M. Schulhof calls attention to the fact that the orbit of Holmes' comet resembles that of De Vico, 1844 I. The criterion of Tisserand

$$n = \frac{1}{a} + \frac{2\sqrt{Aj}}{Kj^2}\sqrt{p}\cos i,$$

in which *n* is constant through all modifications of the orbit by a single disturbing body, is quite completely satisfied.

	n	*π*	☊	*i*	*e*	*a*	*lj*
		°	°	°			°
Comet Holmes..........................	0.532	345	332	21	0.41	3.63	149
Comet de Vico 1678................	0.542	323	163	3	0.63	3.07	143
Comet de Vico 1844 I..............	0.537	343	64	3	0.62	3.10	163

Comet 1892 I (Swift) is still visible with a 16 inch telescope. It is faint round, 30″ in diameter, with a slight condensation in the center. Miss F. Gertrude Wentworth's elements of the orbit (*Astr. Jour.* No. 273) represent the observations closely. On Jan. 16, the corrections to the ephemeris were + 1^s in R. A. and — 1.6′ in Decl.

Ephemeris of Comet 1892 I (Swift).

[Computed from Miss Wentworth's elements (*Astr. Jour.* No 273) by H. C Wilson and Miss C. R. Willard].

Gr. M. T. 1893.		App. R. A. h	m	s	App. Decl. °	′	″	log *r*	log Δ	Br.
Feb.	5.5	0	40	45.8	+ 25	23	50	0.62277	0.65664	0.004
	9.5		44	34.6		22	43	0.62702	0.06558	
	13.5		48	25.3		23	03	0.63121	0.67419	.004
	17.5		52	17.7		24	44	0.63534	0.68248	
	21.5	0	56	11.4		27	40	0.63943	0.69064	.004
	25.5	1	00	05.8		31	42	0.64346	0.69808	
Mar.	1.5		04	01.8		36	45	0.64745	0.70539	.003
	5.5		07	56 2		42	48	0.65138	0.71238	
	9.5	1	11	51.6	+ 25	49	43	0.65527	0.71906	0.003

Ephemeris of Comet 1892 II (Denning).

[From *Astr. Nach.* 3140].

Berlin M. T. 1893		App. R. A. h	m	s	App. Decl. °	′	log *r*	log Δ	Br.
Feb.	5.5	4	04	53	— 17	35.6	0.5630	0.5345	0.15
	9.5		04	29	17	30.6			
	13.5		04	24	17	24.7	0.5711	0.5570	0.13
	17.5		04	37	17	18.0			
	21.5		05	08	17	10.8	0.5791	0.5781	0.12
	25.5		05	54	17	03.3			
Mar.	1.5		06	56	16	55 7	0.5870	0.5979	0.10
	5.5		08	11	16	48.3			
	9.5		09	39	16	40.8	0.5947	0.6163	0.09
	13.5		11	16	16	33.7			
	17.5		13	07	16	27.2	0.6023	0.6333	0.08
	21.5		15	07	16	21.2			
	25.5		17	16	16	15.9	0.6098	0.6489	0.07
	29.5	4	19	33	— 16	11.2			

Ephemeris of Comet 1892 IV (Brooks Aug. 28).

(From *Astr. Nach.* No. 3131.)

1893		App. R. A. h	m	s	App. Decl. °	′	log *r*	log Δ	Br.
Mar.	1	18	06	02	— 38	44.9	0.1586	0.1504	5.53
	2		07	54		36.4			
	3		09	44		27 8			
	4		11	30		19.3			
	5		13	13		10.7	0.1723	0.1534	5.12

	R. A.			Decl.		log. *r*	log Δ	Br.
	h	m	s	°				
Mar. 6	18	14	53	− 38	02.1			
7		16	30	37	53.5			
8		18	04		44.9			
9		19	34		36.3	0.1859	0.1559	4.75
10		21	01		27.7			
11		22	25		19.2			
12		23	46		10.6			
13		25	04	37	02.1	0.1992	0.1578	4.43
14		26	19	36	53.5			
15		27	31		45.0			
16		28	40		36.4			
17		29	47		27.9	0.2122	0.1591	4.15
18		30	50		19.4			
19		31	51		11.0			
20		32	48	36	02.5			
21		33	42	35	54.0	0.2249	0.1599	3.90
22		34	33		45.7			
23		35	20		37.4			
24		36	05		29.1			
25		36	47		20.8	0.2373	0.1602	3.68
26		37	26		12.5			
27		38	02	35	04.2			
28		38	35	34	55.9			
29		39	06		47.7	0.2494	8.1602	3.48
30		39	33		39.6			
31		39	57		31.5			
Apr. 1		40	18		23.4			
2		40	36		15.5	0.2613	0.1599	3.30
3		40	52		07.7			
4		41	06	34	00.1			
5		41	18	33	52.7			
6	18	41	27	− 33	45.4	0.2728	0.1597	3.13

Comet 1893 I (Brooks, Nov. 18.)—This comet is an easy one to observe with a small telescope. Its motion has been quite rapid. Since Dec. 23, it has been above the circle of perpetual visibility, but it is now going rapidly south. The elements which appear to best represent the observations thus far are the following by M. P. Maitre in *Astr. Nach.* 3138. The ephemeris which follows was computed by Mr. A. G. Sivaslian from these elements.

ELEMENTS OF COMET 1893 I.

$$T = 1893 \text{ Jan. } 6.5355 \text{ Paris M. T.}$$

$$\left.\begin{aligned}\omega &= \ \ 85^\circ\ 15'\ 05''.4\\ \Omega &= 185\ \ \ 39\ \ \ 05\ .6\\ i &= 143\ \ \ 52\ \ \ 16\ .4\end{aligned}\right\}\ 1892.0$$

$$\log q = 0.077328$$

Ephemeris of Comet 1893 I (Brooks Nov. 19).

Gr. M. T.	R. A.			Decl.		log *r*	log Δ	Br.
	h	m	s	°	′			
Feb. 5.5	0	03	50	+ 32	17.6	0.1084	0.1483	1.78
6.5		05	55	31	40.1			
7.5		07	55	31	04.2			
8.5		09	49	30	29.8			
9.5		11	39	29	56.9	0.1164	0.1834	1.47
10.5		13	25	29	25.4			
11.5		15	06	28	55.1			
12.5		16	44	28	26.1			
13.5		18	19	27	18.3	0.1250	0.2154	1.22

Gr. M. T.	R. A.			Decl		log *r*	log *Δ*	
	h	m	s	°	′			
Mar. 14.5	0	19	51	+ 27	31.6			
15.5		21	20	27	05.9			
16.5		22	47	26	41.2			
17.5		24	11	26	17.5	0.1340	0.2446	1.02
18.5		25	33	25	54.7			
19.5		26	52	25	32.7			
20.5		28	09	25	11.5			
21.5		29	25	24	51.2	0.1436	0.2713	0.86
22.5		30	39	24	31.5			
23.5		31	50	24	12.5			
24.5		33	00	23	54.2			
25.5		34	09	23	36.6	0.1534	0.2956	0.74
26.5		35	17	23	19.5			
27.5		36	23	23	03.0			
28.5		37	28	22	47.0			
Mar. 1.5	0	38	32	+ 22	31.6	0.1635	0.3178	0.64

New Minor Planets 1892 S, T, U and V.—These were all discovered by photography in December, the first three on plates exposed by Charlois at Nice and the last by Wolf at Heidelberg.

		Photograph.			First Observation.									
1892	By	At	Date.	Mag.	Gr. M. T.			R. A.			Decl.			
						h	m	h	m	s		°	′	″
S	Charlois	Nice	Dec. 8	13.5	Dec. 10	7	22.2	4	34	10.7	+	27	23	18
T	Charlois	Nice	Dec. 9-10	10.0	Dec. 11	7	04.8	4	54	14.3	+	31	37	48
U	Charlois	Nice	Dec 14	12.0	Dec. 15	6	46.7	4	47	32.5	+	12	15	40
V	Wolf	Heidelberg	Dec. 16-18	11.5	Dec. 20	9	46.0	5	49	43.2	+	20	23	34

NEWS AND NOTES.

In this number bills will be found for renewal of subscription for the year 1893, for such as have not already done so. It is very desirable that the publisher be notified promptly whether or not subscribers desire the continuance of this journal for the year 1893. For information see "Publishers' Notices" at the end of this number. Foreign subscribers will please notice a small increase in price to cover postage occasioned by recent increase of size to be maintained in the future.

The French Academy of Sciences honors E. E. Barnard with the Lalande Gold Medal.—At the meeting of the Academy of Sciences of France held December 19, 1892, E. E. Barnard of Lick Observatory was honored by the award of the gold medal for his astronomical discoveries, especially for his recent discovery of the fifth satellite of Jupiter. This new member of the Jupiter system was found last September by the aid of the great telescope at Mt. Hamilton. It has since been seen by some smaller instruments in this country, viz., the refractors at the University of Virginia, Princeton and Evanston, but it is much the faintest, and the most difficult body known in the solar system, and probably it would not have been discovered with a less powerful telescope. The smallest instrument with which it has yet been seen is 18½ inches aperture, the Clark refractor of Dearborn Observatory.

It may be of interest to some of our readers to know that the Lalande medal is given only to original discoverers and investigators in astronomical fields, and it is probably the highest recognition of merit from the learned societies in the world. It has only been given to experienced astronomers when some great discovery has been made. In 1890 this prize was awarded to Schiaparelli of the Royal Observatory of Milan, for his observations determining the rotation time of Mercury and Venus. Mr. Barnard's new satellite of Jupiter has been regarded in this country and in Europe as the most brilliant discovery of the age. The readers of this journal generally know that Mr. Barnard stands at the head in comet discoveries in the world, and that he was first to discover a comet by the aid of photography. His ability as an astronomer is also recognized by the fact that several of the leading observatories of the country are anxiously ready to give him place, if he cares to consider their offers.

Harvard College Observatory, Arequipa, South America.—In a private letter under date of Nov. 29, Professor W. H. Pickering writes of his absence from Arequipa in the interior of South America, for the purpose of latitude and longitude determinations. He has also measured the height of some of the principal mountains, presumably the highest on the continent.

In speaking of the October number of this publication Professor Pickering comments quite at length on the article by M. Deslandres, and expresses great pleasure in its perusal.

Since his return to Arequipa he speaks of being busily engaged with observations upon the rotation of Jupiter's first and second satellites, and with observations on the planet itself. In connection with his study of the satellites he already suggests some new things that he promises to speak of soon in a communication to this periodical.

Double-Star Orbits Recently Computed by Glasenapp.—Professor Glasenapp is continuing his investigation of the orbits of binary stars. He has recently published (*A. N.* 3119) the orbits of β 883 (period 16.35 years), 8 Sextantis, discovered by Alvan Clark (period 93.92 years), and φ Ursæ Majoris (period 115.4 years). The last named is OΣ 208. He has also recomputed the orbit of β Delphini (β 151), using the recent measures of this rapid system, which will soon be published.

85 Pegasi.—Prof. Glasenapp has recently recomputed the orbit of this interesting binary (β 733) and reduces the period to 17.48 years. This pair was discovered with the Chicago 18½-inch in 1878. It is a difficult pair at all times, as the components are very unequal, and the maximum distance is only 0″.8. All of the positions are by Burnham and Schiaparelli, with the exception of three sets of measures by Hall. The elements were calculated in 1889 by Schaeberle, and a period of 22.3 years found. It has been measured each year at Mt. Hamilton since that time, giving data for a more accurate result. The observed and computed positions agree remarkably well in Glasenapp's orbit, and the error in the periodic time may be assumed to be a small one. There are but five binaries known with periods of less than twenty years. OΣ 535, β 989, β 883, β 733 and ζ Sagittarii. The period of the last named pair is not altogether certain. Celoria found 16 years for β 151, but this has been shown to be too short.

Double Star Measures by Leavenworth, 1892.—Professor F. P. Leavenworth has recently published in the *Astronomical Journal* his last micrometrical measures of double stars at the Haverford College Observatory. The measures were all made in the first half of 1892 with the 10-inch equatorial. The list of stars comprises about 90 pairs, the majority of them being β stars, for which there are no recent measures.

Western Union Time;—The unreliability of the Western Union Time service, so-called, for railway companies and jewelers is being shown more and more the longer it is tried. Recently the clock controlled by this telegraph company on Washington time, as it is claimed, has been ordered out of the Union Depôt at Duluth because the Superintendent of this Depot claimed that the time was unreliable. The same thing has been repeatedly reported in the publications from other prominent cities in the United States.

The telegraph company assumes to distribute the standard time of the Naval Observatory at Washington to all points in the United States for the use of railroad companies and commercial business generally, at certain prices named by such company. This time is obtained directly or indirectly through a certain clock company in New York, and the telegraph company therefore uses the clocks manufactured by that company only. For a similar reason the Western Union Company will use time from Washington only. At least Washington time only is claimed to be used. This matter has been tested somewhat. The time of local observations has been offered to the telegraph company free of charge and such offers have been refused. It certainly would be more convenient for the telegraph company to use local Observatory time that necessarily goes into its general offices from the wires of railroad companies that take the time of local observatories and do not patronize the Western Union time. But the company has refused to take the local Observatory time when offered free of charge. Now, why is this? Plain enough when the whole plan of this business is understood. It is not because Washington time does not cost anything. It is not because the best time service is cared for by the telegraph company. It is not because the best controlled clocks are offered to its patrons, for the contracting parties had better ones in their possession when this time distribution began. What is the root of the matter? The present administration of this Government is about to change, and it is a good time for the friends of Colleges and local Observatories to understand the detailed history of this Western Union deal, and to see if some egregious wrongs can not be righted, even though it makes some officials in high places at Washington a little uncomfortably warm.

Position of Nova Aurigæ for Nov. 1892, by Barnard.—In *Monthly Notices* for Nov. 1892, Prof. Barnard has a paper on Nova Aurigæ, giving a brief account of his discovery of the nebulous character of this star in August last, and the results of his measures of the companion stars in the field. These stars were carefully measured by Burnham shortly after the discovery of the variable. The agreement generally is very close, but Barnard makes the distance of E about a quarter of a second greater, which would seem to imply some proper motion on the part of the faint companion.

Motion of Σ 2525.—Mr. Burnham published a paper on the motion of Σ 2525 in *Monthly Notices* for December 1891, giving all of the measures of this pair down to that time, with a graphical representation of the relative change. Mr. J. E. Gore has used these observations, together with a later set of measures made with the Lick telescope in 1892, to compute the orbit by the Glasenapp method. (*Monthly Notices*, Nov. 1892) and finds a period of 138.54 years. He places the smaller component in the fourth quadrant. It is a difficult pair, the distance now being only 0″.2.

J. M. Schaeberle of Lick Observatory planned to start for South America Jan. 25 to observe the total eclipse of the Sun, April 15–16.

γ Coronæ Australis.—Professor Sellors, of the Government Observatory at Sydney, contributes a new orbit of γ Coronæ Australis to the last number of *Monthly Notices*. Using all the measures down to and including 1891, he finds a period of 121.24 years. Gore, with the same range of measures, gave a very different result (*Monthly Notices*, May, 1892), his period being 154.41 years. In the last ten years no less than four other orbits have been computed, with periods varying from 55 to 93 years. It is difficult to account for these wide discrepancies, as this is a very easy pair at all times, and the measures should be of the highest accuracy. It is evident that for some time to come, careful observations are much more important than new elements.

New Director for Haverford College Observatory.—Professor W. H. Collins has succeeded Professor F. P. Leavenworth as Director of the Haverford College Observatory. The latter resigned last summer to take the chair of astronomy in the University of Minnesota. Professor Collins will continue the double star work which he has been engaged in for several years past under the former director.

New Nebula.—Professor Swift writes in the August number of ASTRONOMY AND ASTRO-PHYSICS about a new nebula independently picked up by Professor Barnard and myself in α, $3^h\ 56^m\ 20^s$; $\delta + 69° 30'$ (1890), and about two degrees S. E. of the star Gamma Camelopardi. He claims to have seen this nebula many years ago with his 4½-inch comet-seeker. My purpose now is not, however, to discuss the question as to priority of discovery but to mention that, while comet-seeking on August 19 last, I was surprised to find another new nebula not far distant from the one before alluded to. It is rather faint, with nucleus about 12th magnitude, and very small, but it was sufficiently conspicuous to be discovered with a power of 40 only on my 10-inch reflector. The position of the nebula is

$$\alpha\ 3^h\ 36^m\ 15^s,\ \delta + 67° 45' \ (1890).$$

My determination of the place is not likely to be very accurate as I have no good observations of the comparison stars. A small nebula discovered by Professor Swift, No. 1469 of the New General Catalogue, lies in the region closely contiguous, for it is only 1¼ degrees E. N. E. of the new object.

Bristol, England, Jan. 1, 1893. W. F. DENNING.

The Telescope of the Future.—When in 1825 the Dorpat refractor of 9½-inches aperture was constructed, it was considered a masterpiece, writes Alvan G. Clark in the *North American Review*, and it was considered the limit had been reached. Guinard, however, had made better glass possible, and Fraunhofer better workmanship. As a consequence there were constructed in 1845 two object glasses of 15 inches aperture. But this limit was again surpassed when we succeeded in procuring discs for an 18¾-inch glass, which were figured and sent to Chicago. Then followed the 26-inch lenses of the Washington and McCormick Observatories, the 30-inch of the Pulkowa, and finally the great 36-inch lens of the Lick Observatory.

It must be remembered that the ground had been disputed inch by inch, and that with each succeeding advance the limit of successful glass melting was thought to have been attained. Even quite recently a noted optician, speaking of the possibility of obtaining discs larger than 36 inches, said it appeared to him that the chances of obtaining 40-inch discs in the present state of the art were remote. And yet there are now in my manufactory two remarkably fine discs of 40 inches diameter ready for figuring.

Who then shall set the limit to this phase of the art considering the great possibilities of scientific improvement and advance of the present day, in view of what has been already accomplished?

Students' Work at the Underwood Observatory. The Underwood Observatory, in connection with Lawrence University at Appleton, Wis., was fully equipped for work at the opening of the present College year. The outfit consists of a ten-inch Clark equatorial, a four-inch meridian circle, a mean time and a sidereal clock, a sidereal chronometer, a chronograph, a spectroscope and filar position micrometer. A local time service has been established in connection with the Observatory.

The Observatory work is elective, and restricted to the Senior class in order that the number be sufficiently small to give each student plenty of time with the instruments.

During the present term, two lines of work are being pursued, viz. ,time and double-stars. For this work the class is divided into groups of twos, one group working with the meridian circle and one with the equatorial each night; by this arrangement, each member of the class has four nights per week with the instruments, two nights with the equatorial and two with the meridian circle.

Each student is required to determine the sidereal time by his own observations, convert the same into mean solar time and determine the error of the mean time clock, which error is not allowed to reach a single second.

In double star work each student makes a catalogue of all stars observed, the data contained being the R. A., Dec., Position Angle and Distance.

They are held to a star until they can not only measure it twice alike, but do it correctly.

L. W. UNDERWOOD.

Planisphere by M. W. Harrington.—Recently Professor M. W. Harrington, formerly director of the Observatory at Ann Arbor, and now Chief of the Weather Bureau, Washington, D. C., has prepared a movable planisphere showing the constellations and the principal stars in each, conveniently related by lines to assist in tracing them. The old mythological figures have been omitted. The names of the bright stars are given, those having less magnitude are indicated by the Greek letters in the usual way, while the faintest are shown by dots in their proper places without designation, including some stars of the fourth magnitude. The printing is white on dark blue paper, securely mounted on heavy board. The circular card is a little more than ten inches in diameter and turns on a central pivot so that it may be set to any hour of the night, and the principal naked-eye features of the sky are in order before the observer's eye. It is an excellent device for self-instruction in regard to the places and names of easy celestial objects that any student or teacher might easily know, if only disposed to spend half-hours occasionally looking at the evening sky with this planisphere in hand as an inexpensive and a ready guide.

This planisphere has an important feature that we have not seen in others with which we are acquainted, and that is, a means of identifying the planets. Upon its reverse side tables are given with easy directions, so that the planets, Mercury, Venus, Mars, Jupiter, Saturn and Uranus, can be found when visible to the unaided eye.

The publishers of this planisphere are The Register Publishing Company of Ann Arbor, Michigan. Attention is called to the advertisement elsewhere given.

C. H. Rockwell, of Tarrytown, N. Y., is to spend a portion of the winter in California.

The Astronomical and Physical Society of Toronto.—At its last meeting in 1892 of the Astronomical and Physical Society of Toronto, the attendance was large. A communication was read from Mr. Maunder, of Greenwich, England, in which favorable mention of Flammarion's recent publication on Mars was made; a letter from M. L. Niesten of Berlin in regard to the globes of Mars that he makes; also from Dr. M. A. Veeder on Auroræ. Under the head of predictions for the first part of January a very complete list of useful current phenomena was named. The annual meeting of the Society was to be held on 10th January, 1893.

The title of the paper for the evening was "Before the Beginning," and was read by John A. Paterson. It consisted of a review of the nebular theory by LaPlace, with references to Dr. Morrison's illustration, Dr. Croll's theory, and the changeful state of the stuff of which the visible universe is made, in the process of time, with some speculation as to the condition of it prior to the date of the beginning of the La Place theory. The place given to the collision theory is possibly too prominent, if the brief review of the paper which we have seen is just.

The Library of Columbia College Observatory has for sale a set of *Astronomische Nachrichten*, Vols. 4 to 123 inclusive. All the volumes are in perfect condition, and mostly well bound. Address Harold Jacoby, Columbia College, New York, U. S. A.

Chambers' Handbook of Astronomy.—A subscriber wishes a good second hand copy of Chambers' handbook of Astronomy, third edition, possibly fourth edition, if not too expensive. Give information to this office.

W. E. W., Architect's office, Capitol, Washington, D. C., has one of Fauth's position micrometers for sale, at such figures as may make the purchase an object for any one wanting such an instrument. Particulars may be learned through the address given above.

BOOK NOTICES.

Introductory to Modern Geometry of Point, Ray, and Circle. By William Benjamin Smith, Professor of Mathematics and Astronomy, University of the State of Missouri. New York: Messrs. Macmillan & Co, publishers, 1893.

Only a cursory examination of the subject matter of this new book shows that it is written for a very practical purpose, with the aim to present in a simple form, a body of geometric doctrine that should be a standard for admission to college, and a knowledge of which is required of Freshmen for entrance to the University of the State of Missouri. In its preparation the author, in carrying out his aim, has had reference both to the amount and the kind of matter to be introduced. Whether he is right in either of these important particulars is a grave question now already before the minds of the best mathematicians and teachers of higher education in this country. The movement set on foot a few months ago by the National Educational Association to discuss and determine in the broadest way possible, what should be the proper preparation for a student seeking admission to college, was certainly one of the wisest things that could have been undertaken at the present time. A proper uniform standard for admission to college is, and ought to be a national one, and the manner in which the discussion is going on among influential teachers, scholars and authors gives strong promise of early and important results. One of the nine topics named for this discussion is mathematics, and the branch of geometry is doubtless the leading one to claim attention. Anything new or better in regard to this branch at this time ought to be examined critically and most thoroughly. For one we are glad that Professor Smith has published this new book. For it is a challenge to some of the matter and some of the method of teaching the elements of geometry in common use. The first 20 pages is the introduction, which is occupied with geometry as the doctrine of space. Then follow the themes of convergence, triangles, parallelograms, concurrents, symmetry, circle, the circle as an envelope, constructions and exercises. Thus 140 pages is devoted to linear relations. The remainder of the book (150 pages), is given to areal relations, in which the following topics appear: area, criteria of equality, miscellaneous applications, squares, propoition, similar figures, constructions, the traction problem, metric geometry, measurement of the circle, measurement of angles, the Euclidian doctrine of proportion, maxima and minima. This book is one of merit. The novelty of its methods needs to be tested in the class-room. In the hands of a competent teacher there is little doubt but that excellent results will follow.

The Academic Geometry. By William F. Bradbury, head master of the Cambridge Latin School. Part I, Plane Geometry. Messrs. Thompson, Brown & Company, Publishers. Boston, 23 Hawley St., pp. 220.

This new book contains the important theorems of plane geometry. It employs good models of demonstration with numerous exercises to test the knowledge of the pupil as he advances. The hints to teachers to aid them to get into the spirit of geometry, in order to teach are excellent. The full list of exercises at the close of the book affords ample scope for review to fix in mind the elements of Plane Geometry well to aid in further study of mathematics.

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ASTRONOMY AND ASTRO-PHYSICS. PLATE XVI.

HOLMES' COMET, NOV. 8, 1892. EXPOSURE 3 HOURS.
E. E. BARNARD, LICK OBSERVATORY.

Astronomy and Astro-Physics.

VOL. XII, No. 3. MARCH, 1893. WHOLE No. 113

GENERAL ASTRONOMY.

THE PLANET JUPITER AND ITS SATELLITES.*

WILLIAM H. PICKERING.

Advantage was taken of the past favorable opposition to make a careful study of this planet, and of each of the well known members of its family. Owing to the small size of our telescope, it has been impossible to observe Mr. Barnard's recently discovered satellite, but the steadiness of our atmosphere has enabled us to study the other members of the system under very favorable circumstances.

JUPITER.

The first subject which absorbed our attention was an investigation of the nature and appearance of the spots and belts. Various magnifying powers were employed, but 450 diameters gave, on the whole, the best results. Under the most favorable visual conditions, it appeared that the surface of the planet consisted of a uniform white mass of cloud, and that over this stretched a thin, gauzy veil of a brown material, in structure not unlike our cirrus clouds. This covered the entire surface of the planet from pole to pole, but was more dense in some places than in others. Where it occurred in dense masses it formed the belts, where it was thin, we had the spaces between them. Occasionally a round or elliptical hole of 1″ to 2″ in diameter, penetrated this layer. If the hole occurred in a belt, it was very conspicuous, but if it occurred between the belts, it was much less so. These holes are the well known white spots upon Jupiter, and are, with one or two exceptions, the only regions that appear entirely clear of the gauzy veil above mentioned. As the white spots seemed to occur indifferently either in or between the belts, it was inferred that they had their origin in the uniform white layer of the planet, and penetrated the cirrus layer from below. There was one narrow white streak parallel to the belts, and not over 1″ in breadth, where the cirrus layer was so attenuated that we

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* Communicated by the author.

could not be sure that it existed at all, but this region apparently differed from the other spaces only in degree and not in kind. The great red spot itself was extremely faint, and with difficulty distinguished. The space above it, however, excepting at its following end, was entirely clear of the cirrus formation, and thus indicated its whereabouts. The spot was, in fact, apparently seen through a hole in the cirrus as if it formed a portion of the white surface beneath. In short, it appears that were it not for this insignificant light gauzy veil of brown cloud, we should find the surface of Jupiter, like that of most of the other planets in the solar system, almost a perfect blank. This gauzy structure must float in a nearly transparent atmosphere surrounding and rising above it, and it is this atmosphere which causes the absorption, and which almost completely obscures the belts at the limb of the planet. A further reference to this atmosphere will be made later on, in describing the phenomena of the satellites.

THE SATELLITES.

We may classify the physical peculiarities of these bodies in the order of the facility with which they may be detected.

(*a*). *Relative Brightness.* The smallest telescope will show that the 3d satellite is the brightest of the four. The others follow in the order 1st, 2d and 4th. Under certain circumstances, as will appear later, the 2d may equal the 1st. Otherwise we have never detected any change in this order. Their mean magnitudes, as given in the Harvard Observatory Annals, Vol. XI, p. 276, are 5.2, 5.6, 5.8 and 6.4.

(*b*). *Size.* It requires a much more powerful telescope to clearly see the discs of the satellites. With such an instrument it is found that the 3d is the largest of them that the 4th is a little inferior to it, and that the two others are much smaller, and follow in the order, 1st, 2d. From this it follows that the 4th is very much darker colored than the other three.

(*c*). *Color.* These observations require a large telescope and a very clear atmosphere. Taking the color of Jupiter between the belts as our standard of white, the 1st and 2d satellites may be described as golden yellow. They are in general almost precisely the same color, but if there is any difference between them the 2d inclines more to green. The 3d is of a greenish yellow color quite different from the other two. On one occasion recently I saw the 2d half way in color between the 1st and 3d. The 4th is dark greenish grey and strikingly darker than the other three. As these are all non-actinic colors, this explains the fact that it requires from two to four times the exposure to secure a satisfactory enlargement of the satellites, that it does to obtain an enlargement of Jupiter itself upon the same scale. Also, that while the 1st and 2d are intrinsically the brightest to the eye, that the 3d requires the shortest exposure photographically.

(*d*). *Phase.* We now come to an observation of which only the most favorably located telescopes are capable, that of watching the change of shape as the satellite enters the shadow of its primary. The difficulty of course increases in the inverse order of the size of the satellite.

(*e*). *Diffraction Spot.* This phenomenon was first noticed at this Observatory in August 1891, and was described in the *Astr. Nach.* 3079. It consists of a black spot visible upon the surface of the satellite, and apparently due to diffraction. If the lens is in perfect adjustment, it is central, otherwise it appears near the edge of the disc. If the seeing is very good the spot is very small but increases in size as the character of the definition diminishes. Its appearance undoubtedly depends more or less upon the size of the satellite and of the objective. We frequently see it upon the 3d satellite, occasionally upon the 4th, but rarely upon the 1st or 2d. Unless all of the above described phenomena can be clearly seen it is probably useless for the observer to attempt to detect those that follow. Neither should he make the attempt with a power much lower than 700 diameters. He should also adjust his objective, if necessary, so that it shall not give the least trace of a wing under the highest power, even when thrown slightly out of focus. Possibly the best way of introducing our results will be to give a brief history of the observations that led up to them.

Upon October 8th of the past year, I began a series of measurements with the 13-inch telescope of the diameters of Jupiter's satellites. Upon the next evening, I undertook to measure the 1st, when at the first glance I noticed to my surprise that its disc was not circular, but very elliptical. A brief computation the next morning showed that if my measurements were correct, that the polar flattening would correspond to a rotation period of about forty minutes, assuming a uniform density. Observations upon the next evening confirmed my first measurements. Some of the other satellites were also measured and I then returned to the first one, when to my astonishment, instead of showing an elliptical disc, it showed one that was perfectly circular, precisely like the other satellites. I could scarcely believe my eyes, but as I continued to watch and measure, I saw the disc gradually lengthen again and assume the elliptical form, and I then understood what had really been found. The 1st satellite has the form of a prolate spheroid or ellipsoid, or in popular parlance is "egg-shaped." The two minor axes are approximately equal, and the satellite revolves about one of them, or as we may say, it revolves "end over end." Within a few days, after this observation had been satisfactorily confirmed, it, with some facts pertaining to the other satellites, was cabled to the States, and published in the *New York Herald.*

Within a week from the date of my first observation, each of the other satellites had been recorded at some time as presenting an elliptical disc. But now a new difficulty arose,—in their cases the ellipticity was much less marked than in the case of the 1st satellite, and my assistant, Mr. Douglass, while readily confirming the ellipticity of the 1st, declared that the others always appeared to him to be circular. Nor was this all, the main difficulty lay in the fact that the three outer satellites when elliptical, appeared shortened equatorially, not lengthened, and this result was confirmed by the micrometer. In other words, these three satellites do not seem to revolve about their minor axes! Their rotation, therefore appears to contradict one of the most elementary principles of physics. It is chiefly for this reason that I have refrained from making any publication since my first telegram. I at first assumed that the result was due to an optical illusion, and tried various experiments, such as using the two eyes alternately, and turning the head through an angle of ninety degrees. The elongation nevertheless remained persistently in the same direction. I next thought the effect might be due to light and dark spots, suitably placed upon the surface. But when the satellites are in transit, and about disappearing, these spots should become visible. Nothing of the sort is seen, however, although surface markings have been discovered upon the 1st, 3d and 4th satellites. It was next suggested that the axes of the satellites might be greatly inclined to the plane of their orbits, and thus cause, not a shortening of the assumed equatorial, but an apparent lengthening of the assumed polar diameter, thus producing the same effect on the eye. The micrometer negatived this theory. Of late, probably owing to training of his eye, Mr. Douglass has been able to confirm my observations upon the three outer satellites, and we now both see them elliptical at the same times, and our position angles agree with one another within a few degrees. A possible explanation of their shape and revolution that has occurred to me is that of an irregular distribution of density in their interiors. This explanation seems improbable, and I therefore merely announce the facts that:

(*a*). The 1st satellite is a prolate ellipsoid revolving about one of its minor axes in a period of $13^h\ 03^m.0$.

(*b*). The discs of the 2d, 3d, and 4th satellites at regular intervals assume the form of ellipses, and this periodic change is presumably produced by a rotation upon their axes.

In dealing with further details the satellites may best be taken up separately:

First Satellite.—The period of rotation of this satellite, as above stated, is $13^h\ 03^m.0$, and this result has been abundantly confirmed by repeated prediction and verification of its ephemeris. It follows from its shape as above described that its disc appears perfectly circular once every six and a half hours. This appearance lasts for half an hour. The remainder of the time it appears more or less elliptical. When at a maximum the major axis exceeds the minor by about ten per cent. Under these circumstances it will be seen that the ellipticity is considerably greater than that of Jupiter. Its equator is inclined to the plane of its orbit a trifle over ten degrees, and the precession of its equinoxes occurs with extraordinary rapidity. A complete revolution probably takes place in about twenty-six days, but further observations are required to make this determination conclusive. The disc bears one or more nearly longitudinal narrow dark markings. The following ephemeris for the month of March, 1893, gives the approximate Greenwich Mean Time at which the satellite assumes the circular phase, and is therefore at minimum brightness:

FIRST SATELLITE.

d	h	m	d	h	m	d	h	m	d	h	m	d	h	m
1	02	03	7	08	07	13	14	11	19	20	16	26	02	21
1	08	34	7	14	39	13	20	43	20	02	47	26	08	52
1	15	05	7	21	10	14	03	15	20	09	19	26	15	24
1	21	37	8	03	41	14	09	46	20	15	51	26	21	56
2	04	09	8	10	13	14	16	17	20	22	22	27	04	27
2	10	40	8	16	45	14	22	49	21	04	53	27	10	58
2	17	11	8	23	16	15	05	21	21	11	25	27	17	30
2	23	43	9	05	47	15	11	52	21	17	57	28	00	02
3	06	15	9	12	19	15	18	23	22	00	28	28	06	33
3	12	46	9	18	51	16	00	55	22	06	59	28	13	04
3	19	17	10	01	22	16	07	27	22	13	31	28	19	36
4	01	49	10	07	53	16	13	58	22	20	03	29	02	08
4	08	21	10	14	25	16	20	29	23	02	34	29	08	39
4	14	52	10	20	57	17	03	01	23	09	05	29	15	10
4	21	23	11	03	28	17	09	33	23	15	37	29	21	42
5	03	55	11	09	59	17	16	04	23	22	09	30	04	14
5	10	27	11	16	31	17	22	35	24	04	40	30	10	45
5	16	58	11	23	03	18	05	07	24	11	11	30	17	16
5	23	29	12	05	34	18	11	39	24	17	43	30	23	48
6	06	01	12	12	05	18	18	10	25	00	15	31	06	20
6	12	33	12	18	37	19	00	41	25	06	46	31	12	51
6	19	04	13	01	09	19	07	13	25	13	18	31	19	22
7	01	35	13	07	40	19	13	45	25	19	50			

Second Satellite.—This satellite has given us more trouble than any of the others, and has proved to be a very difficult object to observe. At times it appears circular, and at times slightly elliptical. Sometimes the major-axis lies in the direction of the orbit, and at other times at right angles to it. This appearance has been further confirmed by micrometric measurements. The ellipticity is decidedly less than that of the 1st satellite. Its shape in short appears to be that of an ellipsoid of three unequal axes, revolving about the middle one. Its equator lies in the plane of its orbit. No surface markings have been detected upon it. Its period of rotation is $41^h\ 24^m$, or about an hour short of the time required to complete half a revolution in its orbit.

A curious observation was made in connection with this satellite upon the night of December 11. The satellite was about to be occulted, and was decidedly shortened equatorially at the time. Owing to the inclination of its orbit to the line of sight it did not pass behind the center of the planet, but somewhat above it, the position angle between the point of contact and the planet's equator being estimated at about thirty degrees. The satellite retained its shape until almost in contact with the limb, when the major axis of its ellipse suddenly changed its position angle through thirty degrees, becoming parallel to the limb of the planet. Now the interest of this observation lies in the fact that this is just the sort of change that we should expect would be produced if Jupiter were surrounded by a comparatively rare atmosphere, extending several hundreds of miles above its surface, such as presumably extends several thousand miles above the suface of the Sun and thirty or forty miles above that of the Earth. The observation is a very difficult one, however, and whether the change of shape was real or only apparent must be settled by subsequent research.

The following ephemeris for the month of March, 1893, gives the approximate Greenwich mean time at which this satellite presents the smaller of its two elliptical phases, that is, the one in which the minor axis is parallel to the plane of its orbit. Under these circumstances it shines with its minimum brilliancy.

SECOND SATELLITE.

d	h	d	h	d	h	d	h
1	15.2	9	09.5	17	03.8	24	22.1
2	11.9	10	06.2	18	00.5	25	18.8
3	08.6	11	02.9	18	21.2	26	15.5
4	05.3	11	23.6	19	17.9	27	12.2
5	02.0	12	20.3	20	14.6	28	08.9
5	22.7	13	17.0	21	11.3	29	05.6
6	19.4	14	13.7	22	08.0	30	02.3
7	16.1	15	10.4	23	04.7	30	23.0
8	12.8	16	07.1	24	01.4	31	19.7

Third Satellite.—On account of its size and brightness this is much the easiest satellite to observe. Indeed even the occasionally elliptical shape of its disc has been noted by Lassell, Secchi, and Burton. None of these observers, however, seem to have been able to repeat their observations with sufficient frequency or precision to construct an ephemeris from them, or determine the inclination of the axis. When the disc is most elliptical the major axis exceeds the minor by about $0''.2$, a very appreciable quantity. The satellite appears to be of the shape of an oblate spheroid (like a watch), revolving about one of its major axes. Its equator is inclined about eighteen degrees to the plane of its orbit, and it presents the elliptical phase twice in each revolution about its primary. Like our Moon, therefore, its period of rotation coincides, at least approximately, with that of its revolution in its orbit. The time at which it reaches its maximum ellipticity occurs thirty-four hours after inferior and superior conjunction. Its surface markings are readily seen, especially during transit, the most conspicuous being a dark belt situated in the northern hemisphere, and inclined about fifteen degrees to its orbit. The position angle of the belt was determined upon a different date from that of the direction of the minor axis of the ellipse, and it is quite possible that the two are really parallel. There is some evidence also, from the shape of the belt that the south pole of the satellite is inclined towards us ten or more degrees, which would materially increase the inclination of its equator to its orbit. There are also indications of a rapid precession, since the position angle of its major axis appears to vary. Various dark lines and shadings spread southward from the belt, some of them uniting in part, at least, to form a southern belt parallel to the northern one, but less strongly marked. At times the southern pole has appeared somewhat brighter than the rest of the surface, but never brilliant as in the case of Mars. Like our

Moon and Mars the limb is rather brighter than the center of the disc. The following ephemeris, constructed like the preceding ones, indicates the time at which the satellite presents the maximum elliptical phase, and when it is consequently at minimum brilliancy during the month of March, 1893:

THIRD SATELLITE.

d	h	d	h	d	h	d	h
2	06						
5	20	13	00	20	05	27	09
9	10	16	14	23	19	30	23

Fourth Satellite.—This satellite usually presents a circular disc, but at conjunction with Jupiter it is elliptical, the major axis lying nearly perpendicular to its orbit. Its periods of rotation and orbital revolution are therefore identical. Its color is so dark that its surface markings are only seen with the greatest difficulty. They seem to consist chiefly of a broad, dark equatorial belt, the poles being slightly lighter and more greenish in color. The north pole has been seen much brighter than the south, but is not always so. Occasionally it has been thought that very minute dark and light spots have been detected upon its disc, the latter near the north pole. Webb states that he frequently has seen the 4th satellite surpass the 3d in brightness. Such an observation would certainly be of the greatest interest at the present time, and could only be accounted for either by the third becoming still darker in color than the fourth is at present, or by extensive white spots appearing upon the fourth, which latter hypothesis seems the more probable of the two. This satellite will exhibit a slight minimum of brilliancy upon the nights of March 8, 17, and 25.

At times the discs of the satellites have seemed to be of a slightly irregular shape. That is to say, one side of the so-called ellipse has seemed flatter than the other. This has been particularly noticed by Mr. Douglas, though I have occasionally seen it also. I am not inclined to consider it a genuine phenomenon, but rather due to some local cause, such as the action of the wind, combined with slightly inferior definition. No striking instances of change in intrinsic brilliancy from night to night have been noticed in our observations of the satellites, their colors and light not seeming to us more variable in general than that of the other members of the solar system. As far, therefore, as our observations go, I should be inclined to attribute most of the varying phenomena of light and dark transits to variations in the light reflected to us by the clouds on Jupiter, rather than to variations in the brightness of the satellites themselves.

Our micrometric measurements of the diameters have not as yet been completely reduced, but I may say that they confirm those of Engelmann, diminishing the size of each satellite possibly about two hundred miles. This, while increasing their densities slightly, still leaves them at an extraordinarily low figure. Taking the specific gravity of water as our standard, the density of the 1st satellite is less than 1.5, and the density of the 2d, less than 2.5. The densities of the 3rd and 4th satellites lie between these figures. As our telescopic definition is perfect, I do not see how it is possible for these results to be in error. That being admitted, the question arises of what can these bodies be composed? As shown in my paper published in ASTRONOMY for November, 1892, they are too small and too light to retain an atmosphere, excepting at a very low temperature, a temperature, in fact, which could not be very far above that of absolute zero. A low temperature is perhaps not improbable, but of what must the clouds be composed that form their visible surface? If the clouds are formed of liquid drops or bubbles, this liquid can certainly not be water. Besides, these clouds are not white when compared with those upon Jupiter. Shall we conclude that these are clouds of condensed oxygen, nitrogen, or hydrogen? If this hypothesis, taking into consideration the blackness of the 4th satellite, seems improbable, and we dismiss the atmospheric theory altogether, the only solids which are light enough for our purpose, exclusive of the alkaline elements, are those that are porous or hollow. There is still one course left open to us, however. It is that each of these satellites is nothing more than a very condensed swarm of meteorites, like Saturn's ring. The apparent revolution of the 3d satellite about its major axis, which is certainly not a difficult observation to repeat, indicates pretty clearly that there is something peculiar about these bodies, and it is possible that their real constitution may yet admit of mathematical demonstration.

Although it is quite probable that the number of astronomers who will have the optical means to confirm all of these observations is rather limited, yet there is one test that is within the reach of nearly everyone. This depends upon the fact that when the 1st satellite presents a circular disc, and the 2d is elongated equatorially, that there is very little difference between them in brightness, and that, on the other hand, when the reverse conditions prevail, the difference between them is quite marked. The following ephemeris for March has therefore been prepared, Greenwich mean time being employed as before. Upon those dates marked with an * the 1st and 2d satellites will be found to be of approximately equal brightness. Upon those dates marked with a † the 1st satellite will conspicuously excel the 2d in brilliancy.

FIRST AND SECOND SATELLITES.

d	h	d	h	d	h	d	h
2	23.5*	9	09.2†	18	01.5†	24	01.4†
3	09.2†	9	19.2*	18	11.3*	24	11.4*
3	19.2*	12	20.7†	18	21.3†	24	21.3†
4	05.2†	13	07.3*	19	07.4*	28	09.5†
4	15.1*	13	17.3†	19	17.3†	28	19.5*
8	03.4*	14	03.3*	20	03.1*	29	05.5†
8	13.2†	14	13.2†	23	05.4†	29	15.4*
8	23.2*	14	23.6*	23	15.4*	30	01.4†

It is suggested that early observations of the relative brightness of these two bodies may be employed to determine their periods of rotation with considerable accuracy.

AREQUIPA, Peru, Jan. 2, 1893.

SWIFT'S COMET (α 1892).[*]

A. E DOUGLASS.[†]

This comet was first observed here on March 29*d* 21^h, G. M. T. For more than a month the photographic telescopes were turned upon it whenever possible and a large number of photographs were secured. It is owing to the amount of detail shown by these photographs and the evident results to be obtained by their thorough examination that this discussion of the work here has been so long delayed.

The most interesting series of plates were the fifty-six taken in the Bache 8-inch photographic doublet, on a scale of 20 millimeters to the degree. Of these, sixteen chart plates taken on twelve different nights from March 30th to April 27th are of the first quality. In them the definition is good and accurate comparisons can be made between different plates. Seven somewhat in-

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[*] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

[†] First assistant at the Boyden Station, Arequipa, Peru.

ferior plates taken upon five additional nights are sufficiently good for many purposes. Twenty other chart plates were taken which, from various causes, were unsatisfactory. The list is completed by thirteen spectrum plates of which five show five or more bright lines in the nucleus and two show spectra of the tail at about 1° from the head.

The next series in order of interest was taken in the 2.5-inch photographic doublet, on a scale of 3.8 millimeters to the degree. Twenty plates in all were taken, of which twelve are satisfactory and have been used for purposes of measurement.

In addition a number of plates were obtained in the 13-inch refractor and in the 20-inch reflector which in extended study of the comet would be of great use.

A short examination of the Bache plates gave at once two empirical facts: 1st, the tail of Swift's comet was composed of luminous masses receding from the head at a measurable rate, and 2nd, the form of the tail depended largely on some varying force acting at the head.

We will proceed to investigate the first.

For purposes of measuring the velocity of recession from the head, eight points were identified, each point being found upon two plates, and their distances from the nucleus were determined. They may be subject to small errors owing to the hazy outlines of the comet itself. Nevertheless, one case is subject to no uncertainty. It occurs in the plates of April 7th and 8th when a slender curved stem connects the head with a conspicuous and well defined luminous mass at the base of the main tail (c_1 in Fig. 1 below). The results of these measurements are given in Fig. 1 in which the abscissas give the distance from the head and the ordinates show the mean daily motion of recession. The whole is expressed in minutes of arc.

Table I below contains the value of p (in the formula $y^2 = 4px$) for each point, and a weight assigned to it depending on its accuracy of identification. The mean thus found serves as the basis for the parabola* drawn in Fig. 1.

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* The question of an ellipse in place of this parabola will, it is hoped, be discussed at some future time. For the present, the parabola is sufficiently accurate.

TABLE I. VALUES OF *p*.

Point.	*p*	Weight.	Point.	*p*	Weight.
	′			′	
a	7.2	1	*c*	6.9	1
b	3.6	1	c_1	9.0	6
d	16.2	1	*i*	6.6	1
d_1	0.6	0	*g*	9.3	1
e	7.2	1	*h*	3.3	1

Mean value of p, 8′.2
d_1 is omitted as being probably erroneous.

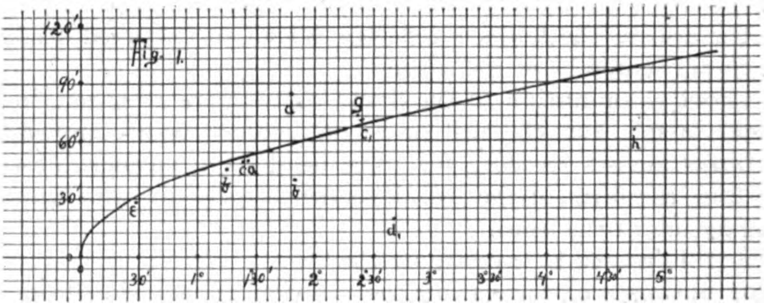
Fig. 1.

Adopting the simple formulas for constantly accelerated motion and an approximate distance from the earth of 100,000,000 miles, the acceleration in miles per day becomes 477,000. Per second it amounts to 0.33 feet.

The second topic—that the form of the tail depended largely on some varying force acting at the head—may be discussed in two parts: 1st, the general characteristics of the tail, and 2nd, the special phenomena within half a degree of the head.

In general, the tail may be described as a bundle of slightly divergent straight streamers, branching from each other and joined to the head by one, two, or three well-marked lines. Measurement of the tail consisted in determining its position angle at different distances from the head. For this purpose, both Bache and 2.5-inch doublet plates were used. The distances employed were 0°.7, 3°.2, 5°.0, 6°.3, and 12°.5. As the maximum difference between the mean position angles at these points was 2°.8, the tail may be described as nearly straight.

Special phenomena near the head exhibit so great diversity of detail that a general description is difficult. Many of the photographs show two brilliant lines leaving the head. The tail may be joined to one, both or neither of these. In the latter case it terminates in one or two slender central lines. The rest of the photographs show a number of faint streamers leaving the head, with the tail sometimes but not always joining one of them. At least two plates show also a very curious twisted appearance of the southern branch of the tail.

Measurements of this part of the comet were first made of the position angle of the best marked line of connection between the head and the outer tail, and second of the position angle of the large jets of luminous matter forming independent tails. Estimates were also made of the duration of the twisting effect on the south side of the tail.

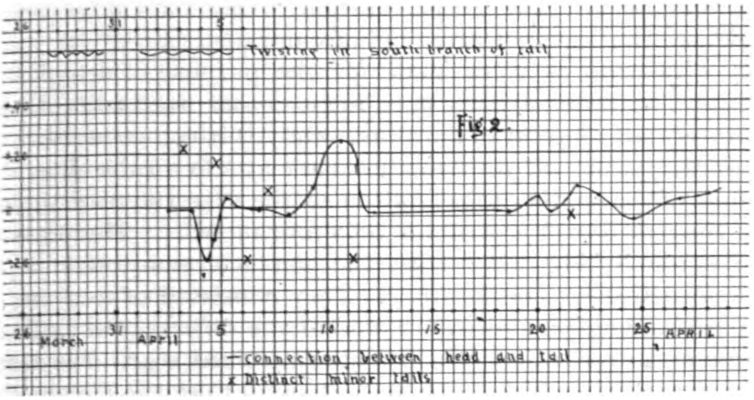

Fig. 2 gives the natural tangents of these position-angles for the date in which they left the head, as obtained by computation. The mean position angle of the whole tail for the date is used as the reference line at 0°.

In the upper part of the figure is given the approximate time in which the twisting effect originated in the nucleus.

The curve as it stands is quite irregular and suggests non-periodic outbursts from the head of the comet, or variations in the repulsive force of the Sun. It will be noticed that where the tail swings to one side there are large jets in the opposite direction, as if the whole resulted from some increase in activity in the head. It is possible that this activity in the comet is connected with solar disturbances in the same way that magnetic storms on the Earth are connected with certain classes of Sun-spots. An examination for such relationship might prove of the greatest interest. If found it would be strong evidence in favor of electricity as the basis of solar repulsion.

OBSERVATION OF THE PARALLAX OF O. ARG. 14320.*

F. P. LEAVENWORTH.

This star has been observed at the Cape of Good Hope; and Prof. Holden has begun a series of photographs for the purpose of determining its parallax. But so far as I know its parallax has not yet been published. It is a star of great promise to the parallax hunter. For its proper motion is 3″.7, and it has a companion star five minutes south of it, affected with exactly the same proper motion. These stars, to be sure, are only of the ninth magnitude, but proper motion rather than brightness is considered the best indication of large parallax.

My observations were made for the purpose of determining whether the star's parallax was large, rather than to determine accurately the amount of parallax. Only thirteen measures were obtained, and not all of these were made at a favorable time. On account of the southern declination of the star the observations were continued over a period of only four months. The measures were made during 1892 with the ten-inch equatorial of the Haverford College Observatory. They consisted of measures of the position angle and distance, and of the difference of right ascension and declination of a neighboring *fixed* star. The parallactic coefficient in declination was so small that the measures of difference of declination could not be used. The resulting parallax from the remaining measures is as follows:

For $\Delta\alpha$,	$+0''.02 \pm 0''.04$
For position angle,	$-0\ .11 \pm 0\ .07$
For distance,	$-0\ .23 \pm 0\ .04$

It is probable that this discrepancy is due to personal equation, as the measures in each set agree well among themselves. Such results are not uncommon in micrometrical work when large distances are measured, and undoubtedly show that the micrometrical method should yield to the photographic.

There is a twelfth magnitude star situated in the direction of the motion of this star, which in the course of about twenty five years will form a double star with it. A single night's observation gave its position

1892.43   188°.7   93″.76

UNIVERSITY OF MINNESOTA.

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* Communicated by the author.

THE BALANCE ROOF FOR TELESCOPE BUILDINGS.*

A. E. DOUGLASS.

A simple form of roof for sheds of limited size has been adopted by us and found to work satisfactorily. A description of it may prove of some interest.

The telescope room is ten feet square, and supplied with the ordinary gable roof. The roof, however, separates into north and south halves which, on specially devised hinges at the lower corners, may be turned completely over and rest in a horizontal position on supports outside. The gable ends also are supplied with hinges, and can be turned inwards to hang down entirely out of sight.

Each half of the roof has a frame of light wood on which is stretched canvas heavily painted. The hinges are half-inch iron pins supported by strong braces at each corner. They are placed several inches from the walls so that nothing may interfere with the free movement of the roof. At the same point a flat iron bar projects from the roof itself some 20 inches beyond the hinge and carries on its end a counterpoise weight of 25 pounds. The weights, though not essential, are nevertheless a most important feature, as they prevent the severe strain a roof of such size would suffer when lifted by one end only. Moreover they enable one to open the roof almost instantaneously, and almost without muscular labor.

Pulleys, ropes, wheels and great weight being avoided there is less chance of its getting out of order, yet it must be provided with fastenings to prevent the wind blowing it to and fro.

The roof is inexpensive and easily made, and can be recommended for use in eclipse expeditions. Owners of small telescopes also might find it well adapted to their requirements.

SOME EFFECTS OF A COLLISION BETWEEN TWO ASTEROIDS.*

SEVERINUS J. CORRIGAN.

Although, for reasons set forth in my communication to No. 112 of ASTRONOMY AND ASTRO-PHYSICS, the minor planets between which has probably occurred a collision that has resulted in the formation of Holmes' comet (or pseudo comet) have not

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* Communicated by the author.

been discovered, and known as members of the asteroid system, I think that certain of the observed phenomena of this remarkable body are, when properly interpreted by means of well known principles of "celestial mechanics," sufficient to give us much valuable information in regard to the several magnitudes of the hypothetical bodies in collision, and to furnish collateral testimony of considerable weight, as to the truth of the hypothesis which was enunciated in No. 111 of ASTRONOMY AND ASTRO-PHYSICS in regard to the origin of Holmes' comet.

One very probable effect of a collision between two such bodies moving with a considerable relative linear velocity, (or of the *explosion* of a single asteroid), would be a complete, or a partial, rupture of one or of both of the moving masses and a dispersion of the resulting particles, in all directions. Considering, first, the particles impelled in a vertical direction, or radially from the center of gravity of the asteroid, it is obvious that if there were no other matter in existence in the surrounding space, the particles thus projected would, after reaching any height, h, due to any initial velocity, u (provided the latter did not exceed an amount definitely depending upon the mass and the radius of the body from which the particles had been ejected), fall back toward the center of gravity of the asteroid, and to the points whence they had been projected. But the existence of any considerable mass of matter in comparatively close proximity to the body whence these particles had arisen would cause a very important change in the motions of such particles. Thus in the case of particles impelled radially from an asteroid, the great mass of the Sun would exert such an influence upon the aforesaid particles, that when the height, h, due to any initial velocity, or impulse, u, attain a value, ρ (dependent upon the mass, m', of the asteroid, relative to that of the Sun, and upon the radius-vector, r, of said asteroid), the ejected matter would not fall back toward the center of gravity of the body from which it had arisen, but would pass under the control of the Sun, move in orbits around that body, and be gradually dispersed in space under its influence. At the height, ρ, the disturbing action of the Sun upon the ejected particles, must equal the direct action of the central body, or asteroid, thereon. Now this disturbing action of the Sun is the difference between the direct action of the solar mass, upon the asteroid, and upon the particles aforesaid. The direct action of the Sun upon the central body is expressed by, $\frac{k^2}{r^2}$, the denominator being the well known constant of acceleration due to the solar mass. The direct action of the Sun upon a particle at distance ρ and exerted along the radius-vector, r, will be $\frac{k^2}{(r+\rho)^2}$, to a sufficient degree of approximation for small values of ρ; the maximum disturbing force of the Sun, upon such particle, must, therefore, be,

$$\frac{k^2}{r^2} - \frac{k^2}{(r+\rho)^2}, \text{ or } \frac{k^2\rho}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (A)$$

The direct action of the central body or asteroid, upon the same particle will be,

$$\frac{m'k^2}{\rho^2} \qquad (B)$$

m' being the mass of the asteroid relative to that of the Sun, which is taken as unity.

Now since at the limit ρ, at which the particles pass from the control of the asteroid into that of the Sun, and begin to disperse in space, under the disturbing action of the latter body, the direct action of the asteroid upon the particles, or the expression (B), must be equal to the disturbing action of the Sun upon the same particles, or to the expression (A), we have,

$$\frac{m'k^2}{\rho^2} = \frac{k^2\rho}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (1)$$

Reducing this equation we will have, to find the mass of the central body, or asteroid in terms of the solar mass,

$$m' = \frac{\rho^3}{r^2} \cdot \frac{2r+\rho}{(r+\rho)^2} \qquad (2)$$

Therefore, all the quantities that are necessary to be known for the determination of the mass of the central body (*i. e.* of the combination of two asteroids in the case of a collision, or of one asteroid if the comet has been caused by the explosion thereof), are the values of r and that of ρ. Now, I purpose to show that from the value of m', as found through equation (2), the diameter of the central body can be found, in terms of that of the Earth, and hence in miles. Knowing m', through equation (2), we can find M, or the mass of the body, in terms of that of the Earth, from this equation,

$$M = \frac{m'}{E} \qquad (3)$$

In which E represents the mass of the Earth relative to that of the Sun, its approximate value being $\frac{1}{326800}$. The relation between volume, mass, and density is expressed by the well known equation,

$$V = \frac{M}{D} \qquad (4)$$

It follows, therefore, that if the density of the central body, relative to that of the Earth, be known, V can be found from equation (4). The relative diameter will then be $V^{\frac{1}{3}}$, and this quantity multiplied by 7913, or the mean diameter of the Earth in miles, will give the diameter of the central body in the same measure. In the practical application of the principles above set forth, to cases such as that of Holmes' comet, the first step is to find ρ, or the radius of the "sphere of control." The following considerations furnish a clue which, I think, leads to a knowledge of this quantity. The greater portion of the ejected particles, lying within the "sphere of control," a condensation or concentration of luminous matter must appear surrounding the central body, or nucleus. The diameter of this condensation will be 2ρ, and if the angular diameter thereof, represented by a, be determined instrumentally when at a maximum, and the geocentric distance, $\varDelta$, of the body at the same time, be known, the value of ρ can be found through the equation,

$$\rho = \varDelta \tan \tfrac{1}{2} a \qquad (5)$$

The valuable observations made by Dr. H. C. Wilson of "Goodsell Observatory," and published in No. 111 of A. AND A. P., indicate that this condensation attained maximum dimensions on, or near Dec. 10, 1892, when it was about 1′ in diameter, and this furnishes the value of a.

The value of $\varDelta$ at the same time was, as I have determined from Schulhof's elements (A. AND A. P., No. 112), 1.85032, and that of the radius-vector r, was, according to the same authority, 2.50828. Therefore the value of ρ found through equation (5) was .000269117, in terms of the Earth's mean distance from the Sun, which is taken as unity. The radius of the "sphere of control" was, therefore, about 25,000 miles.

With this value of ρ and with that of r, as given above, the value of the mass is found through equation (2), to be $\frac{1}{404895000000}$ that of the Sun's mass, and through equation (3), $\frac{1}{1238970}$ that of the Earth. The latter value is that of M, which, through equation (4) gives the volume of the body in terms of that of the Earth, when the density of the former in terms of that of our globe is known. Did space permit it could be shown that the density of the body is probably not very different from that of the Earth, which is taken as unity. Making therefore D unity in equation (4), the volume of the body becomes equal to the mass M above given.

The relative diameter will therefore be $M^{\frac{1}{3}}$, or $\frac{1}{107.4}$, which multiplied by the number of miles in the Earth's mean diameter, (*i. e.* by 7913), gives 74 miles as the diameter of the central body, or asteroid. If this central body be considered as composed of two asteroids of equal sizes, which have combined through a collision, the diameter of each asteroid would be 59 miles. It is known that the diameters of asteroids, in general, are so small that they cannot be well determined by direct measurement, but, from the observed brightness of divers members of the system, it has been approximately determined that the smallest ones are from 20 to 40 miles in diameter, and the largest from 200 to 400 miles. In this connection I would call attention to the fact that the diameters of the hypothetical bodies as determined by the process above set forth, lie close to the former limits, and since, as I have shown, the asteroids concerned in the formation of Holmes' comet must have been unknown and therefore probably small members of the system, this fact is very significant I think.

If we take the mean opposition magnitude of Vesta, the largest member of the system, as 6.0, and its diameter as 400 miles, we can determine the mean opposition magnitude of the body above referred to, and whose diameter is 74 miles, through the following equation,

$$\mu = 6.0 + 2.5 \log \left(\frac{a}{a'} \cdot \frac{\Delta}{\Delta'}\right)^2 + 2.5 \left(\frac{S}{S'}\right)^2 \qquad (6)$$

in which a is the mean distance, Δ the mean opposition geocentric distance, and S the surface of the body aforesaid, and a', Δ' and S' the corresponding quantities appertaining to Vesta. The result is 12.0, which is not far from a mean of the same magnitudes for the whole asteroid system. By using r and Δ as found above for Dec. 10.5, 1892, the theoretical magnitude at that time was about 10.5.

On Nov. 22, 1892, Dr. H. C. Wilson noted the magnitude of the nucleus of the comet as 10.0, while on Dec. 10, 1892, it appeared to him as a star of the 12th magnitude surrounded by a concentration of luminous matter, about 1′ in diameter. Considering that according to the "collision" hypothesis, this matter had been deducted from the nucleus, thus reducing its surface, and therefore its brightness, the relations between the results of observation, and the deductions from the principles above set forth, are very significant, and furnish strong support to the above named hypothesis.

ST. PAUL, Feb. 10th, 1893.

A SIMPLE METHOD OF REDUCING TIME OBSERVATIONS MADE WITH THE TRANSIT INSTRUMENT.*

CHARLES B. HILL.

For Amateur Astronomers.

In these days of accurate time-signals from some neighboring Observatory the amateur astronomer falls into the habit of neglecting his transit instrument, and depending entirely upon the noon signal for his clock error and rate. No matter what care is taken to secure accuracy, I venture to say that a clock rate, carried from the noon signal to the epoch of the midnight observations in connection with which it is used, will frequently be in error more than half a second. The day and night rates of the average chronometer have, usually, very different values.

For certain Observatory work the amateur should observe the nicest accuracy in regard to his local time, which is best obtained (as is well known) by means of a transit instrument. Even a very small transit, approximately adjusted to the meridian, and used with ordinary care, will afford the means of determining the local time with the greatest precision. Only the larger transits, to be found in the more pretentious observatories, may be depended upon to give an accurate chronometer correction by the observation of one or two "time-stars." Smaller sized instruments, such as I am supposing the amateur to use in his work, will twist and squirm under every change of temperature, and in accordance with every imaginable variety of "strain," invisible of course to the observer. For this reason anyone can not obtain an accurate clock correction by the means usually suggested to the amateur: that is, by adjusting the azimuth according to some mark, and levelling the axis with the spirit-level, *and performing these adjustments immediately before observing the selected stars.* It takes some time for any good instrument to settle into comparative stability, and the only way to obtain accurate results with the transit is to make the adjustments as

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* Communicated by the author.

nearly as may be, once for all, and then to leave the instrument entirely alone. Many of the transits sold to amateur workers would be much more useful as instruments of precision, if they had no moving parts for effecting the azimuth and level adjustments.

The proper way to do is to "reduce" each set of observations made with the transit instrument, and to determine from the observations themselves the instrumental constants and the chronometer correction. Without here going into the elementary theory of the transit instrument, let me suggest to the amateur that he review the subject in some standard astronomy, for example, in Professor Young's *General Astronomy*, pages 36-42.

It will then be clear to him that the adjustments of the transit instrument, no matter how carefully made, will never be perfect, but that there will be three principal sources of error, viz.:

(1.) The error of *level.* If the transit axis is not truly horizontal, the arc described in the heavens by the optical axis of the instrument will not coincide with the meridian, but will be a great circle deviating from the meridian most in the zenith, and intercepting it at the north and south points of the horizon.

(2.) The error of *azimuth*, which causes the telescope to revolve in a plane which intersects the true meridian in the zenith.

(3.) The error of *collimation*, on account of which the middle thread does not exactly coincide with the optical axis.

A rigorous discussion of observations made with the transit instrument becomes then a somewhat difficult problem which is fully treated in the different works on spherical and practical astronomy [*vide* W. Chauvenet, Manual of Sph. and Pr. Astr., Vol. II; or W. W. Campbell, Handbook of Pr. Astr., etc.]. I believe that there are many amateur astronomers in the United States who are thoroughly reliable observers, and are capable of doing useful work, but who nevertheless have never had an opportunity for acquiring that knowledge of mathematics necessary to apply the methods given in a text-book of practical astronomy for the reduction of a set of transit observations. Still it is possible with the aid of a few extremely simple algebraic formulæ to obtain from a "set" of stars observed with a portable transit results which will be almost identical with those obtained by a thorough discussion of the same observations according to the most refined methods.

It is proposed in the present paper to describe such a method for the benefit of my fellow amateurs, some of whom may find it useful, as I have. It was learned while in Professor Davidson's office, in the Western Branch of the U. S. Coast and Geodetic Survey, and is derived from different printed and manuscript papers of Charles A. Schott, Esq., Assistant in Charge of the Computing Division.

In order to make the present paper in a measure complete, I append herewith certain easy rules for the

PRELIMINARY ADJUSTMENTS.

It is advisable to reduce the instrumental errors as nearly as possible to zero. This should be done when the transit is first set up; after which the adjustments should be rarely disturbed. The small residual errors will then be reduced from the observations. They are called the "instrumental constants," and are denoted as follows:

a = azimuth error, or constant.
b = level error, or constant.
c = collimation error or constant.

To adjust the level. Place the striding level on the axis and read one end—say the *west* end. Reverse the level and read the *west* end again, being careful not to change the length of the bubble in reversing. Set the *west* end to the mean of these two readings by changing the adjusting screws on the *level.*

To level the instrument. Having performed the preceding operation, bring the bubble *central* by changing the adjustment of the leveling screws on the transit.

Collimation. If this adjustment can be made in the day-time, point the telescope on a distant mark either north or south, and at least a mile away, for good definition. (It is unnecessary to say that the sidereal focus of the instrument must be first determined, and then left unchanged). Pick out some feature of the mark which is exactly bisected by the middle thread. Then reverse the telescope in the Ys and see if the same point is still bisected by the thread; if it is, the collimation is good, if not, move the thread *half-way towards the object* by changing the screws carrying the reticle plate.

Two or three trials of this sort will effect a close adjustment for collimation.

If made in the night, some very close polar star must be substituted for the fixed mark, and the telescope quickly reversed in the Ys. Polaris is, of course, the most suitable star for this operation, with very small instruments, and this star may be observed at any time by shifting the instrument in azimuth. When near

E. or W. elongation, Polaris is the best possible object for this purpose.

Azimuth. The two preceding adjustments can be effected mechanically, but placing the instrument in the true meridian can, originally, be only done by means of the stars themselves. First, find the approximate error of the time-piece by the transit of some star close to the zenith. Then find at what time, by the clock, some close polar star will come to the meridian. At the proper time place the middle wire on the star (by moving the transit "in azimuth")—it will then be approximately in the meridian.

It may be found that the level of the instrument has been changed in this latter operation. If so, that should be again adjusted.

When the azimuth of the transit has been well established, a suitable mark can probably be found (in either direction, north or south) by means of which the adjustment may be effected in future, should it become necessary.

[*Inequality of Pivots.* It may be that the two pivots of the transit axis are not of the same diameter. With the modern instruments this error is hardly appreciable, and may usually be neglected if indeed a value of the constant is not given by the instrument maker. Formulæ for determining the inequality will be found in Assistant Schott's paper on the "Determination of Time, Latitude, Longitude and Azimuth," published by the U. S. Coast and Geodetic Survey, etc.].

In what follows we will consider the simplest way of deducing from all the observations made, the best value for the instrumental constants, and the chronometer correction.

TO REDUCE THE OBSERVATIONS.

Let us suppose a "time set" has been observed in the following manner:—

(1). A certain number of *quickly moving stars*, at least two or three, (say one near the equator, one a little south of the zenith, and one a little north of the zenith), and also *one slowly moving star*, about 15° or 20° from the pole. The striding level should be read at least twice.

(2). Then, the telescope having been reversed in the Ys a similar selection of "time stars," and one "azimuth star." Level readings, as before reversal.

The time of transit over each thread should be recorded in the note book: it is convenient to have this ruled in vertical columns, three or four to the page, as in the form following:

DATE.—APRIL 1, 1884.

Star............	α Urs. Maj.			
Clamp. (or illumination)	E.			
Factors A........	− 0.90			
B........	1.96			
C........	2.16			
	E. W.			
Level D............	43.0 51.0			
Readings R......	59.5 34.5			
Threads 1.........	36.1			
2........	08.9			
3........	41.0			
4........	13.5			
5........	46.2			
6........	18.9			
7........	10 57 51.4			
Mean Thread...	10 56 13.71			
Corrections:				
Rate				
Level				
Collimation				
Azimuth				
Corrected mean				
Tabular R. A.	10 56 36.50			

ΔT

The level readings should be taken in the following manner: Place the level on the axis, and record the reading of the east end, and of the west end. Turn the level 180° (*i. e.* reverse it), place it in the axis again, and record the east and west ends under similar readings of level "direct."

In the preceeding form will be noticed a space for *clamp or illumination.* Some feature of the telescope is taken as a mark to denote the position of the instrument; either the side to which the clamp or the circle is attached, or through which the illumination is allowed to pass, is considered the marked end so that if we have "clamp W" in the first half of the observations, (for example), it will be "clamp E" when the telescope is reversed.

The instrumental errors of azimuth, level and collimation (represented by a, b and c respectively) should be reasonably small, and the value of the level division in seconds of time must be known. The "inequality of pivots" produces no appreciable effect upon the final result when the transit is reversed but allowance for this error will probably produce more harmonious results. When any threads are missed it is convenient to know the equatorial intervals between the threads. This will be illustrated in the annexed "example."

The factors A, B and C represent the effect upon the time of transit of each star for an error of *unity* in azimuth, level and collimation respectively. They depend for their value upon the latitude of the station, and the declination of the star:

$$\begin{aligned} A &= \sin(\varphi - \delta) \sec \delta \\ B &= \cos(\varphi - \delta) \sec \delta \\ C &= \sec \delta \end{aligned}$$

Where

$\delta =$ the declination of the star, and
$\varphi =$ the latitude of the place.

The amateur observer should form a table of these factors for all the principal clock stars, computed for the latitude of his Observatory. He may, without much trouble, compute the factors for declination = − 20°, − 10°, 0°, + 10°, + 20° + 30°, + 35°, + 40°, + 45°, + 50°, + 55°, (and then for each "azimuth star" which he may employ); from the values thus obtained the factors for the different almanac stars can be easily interpolated, with sufficient accuracy for this purpose. Or the factors may be taken out of some general table computed with the arguments, zenith distance, $\varphi - \delta$, and declination. Such a table, computed by Professor Davidson, has been published in pamphlet form by the U. S. Coast and Geodetic survey.*

The observer will, of course, be restricted to the use of those stars for which the apparent right ascensions are given in the Almanac.

The "American Ephemeris and Nautical Almanac" may be procured from the Nautical Almanac Bureau, Washington, two or three years in advance, for the advertised price. It contains the apparent places of 451 stars. It is a first class plan to enter all the stars suitable for the observer's instrument, in a firmly bound blank book (which will open flat), as a working list; with ap-

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* U. S. Coast Survey, 1874. "The Star-factors A, B, C, for Reducing Transit Observations."

proximate Right Ascension, Declination, and Magnitude; and with columns for "zenith distance," "setting," and the factors "A," "B," and "C."

We will now take up the process of reduction, step by step.

1. Find for each star, the time of transit across the "mean wire," which will be simply the average of the transits noted over each separate wire. If the wires are equally distant (and of an odd number, as they should be), this will be the time of transit over the middle wire, within the errors of observation. In this case, if one or more of the wires have been missed we can determine the mean from the first and last, second and penultimate, etc. More properly, we must compute the mean, using the known equatorial intervals, from the following formula:

$$t = \text{mean of observed threads} + \frac{\text{sum of equat. ints. of missed thrds.} \times \text{Sec Dec.}}{\text{number of obsd. threads.}}$$

Sec δ will be recognized as C, the collimation factor, but in multiplying by the natural number it should be carried out to three or four decimal places.

II. Find from the Almanac (pages 302—377), and enter in the record, the apparent right ascension of each star observed, for the night of observation.

III. RATE. If the rate of the time-piece is large (say over $2\frac{1}{2}^{s}$ daily), apply a correction to the mean thread of each star, to reduce all the observations to the same epoch (usually the mean of the R. A.'s of the time stars) let T be the time of transit of the star, and M, the middle time adopted, and let r be the rate of the clock per hour, + when the chronometer is losing, and — when gaining. Then will the correction for each star be equal to $(T - M)r$

IV. LEVEL. The level constant b is found directly from the level readings as follows:

Let W, E be the west and east readings of the level.
W', E' be the west and east readings of the level when reversed.
d the value of one division of the level scale in seconds of arc.

Then $b = \frac{1}{4}\Big[(W + W') - (E + E')\Big]\frac{d}{15}$. The inequality of the pivots, if known, is to be applied directly to this quantity b; the inequality tending to increase $+b$ on one side of the clamp, and to diminish it on the other. Call this corrected level constant b', then is $b'B$ the correction to the observed time of transit of each star for level error.

Note.—The constant b' is always + (positive) when the *west end is too high*; and always—(negative) when the *east end is too high*,—in each case after the proper application of the correction for inequality. The factor B is considered + (positive) for *every* star except one observed *sub-polo*, when it becomes negative.

V. We have now corrected each observed transit for rate and for level error, and this has been done by means of constants directly observed; call the time of transit corrected for these two errors, t.

Then (the tabular right ascension being represented by R. A.), if the instrument were exactly adjusted for collimation and azimuth, the differences (R. A. — t) for each star would contain only the correction to the time-piece, and these differences would vary only by small fractions of a second, representing the accidental errors of observation. But each difference (R. A. — t) contains, besides the clock correction, the combined effect of the errors of collimation and azimuth on the observed transit of that particular star; and our task is now to compare all these separate results with a view to eliminate these two errors. We will call the collimation constant c (which is the amount in seconds of time that an equatorial star would be "out of collimation"), and we will call the azimuth constant a (which represents the amount an equatorial star would be deviated from the true meridian, measured on the horizon).

In computing the observations by the method of least squares we would form as many equations as there were stars observed, and thence derive the three unknown quantities, namely, c, a, and ΔT (the last being the error of the time-piece). Instead of this we will arrive at the instrumental constants by approximation.

Collimation.—If there is no way of assuming c from previous nights' observations we must derive an approximate value from the "time stars." In each position of the instrument clamp E., and clamp W., we have observed one "azimuth star" more or less close to the Pole, and two or three (or perhaps more) "time stars" more or less close to the zenith. Take the average (R. A. — t) for all the "time-stars" clamp E., and the same for clamp W. Then, if the average declination of the stars used is about the same for both sides, any difference between the mean (R. A. — t) E. and the mean (R. A. — t) W. is caused by error of collimation, and this difference will contain the average collimation error of the time stars on *both* sides of the clamp. Therefore, to assume a value for c, we must divide the difference above noted by average C. E. + average C. W. Then will cC be the approximate collimation correction for each star, which must be added to the time of transit on one side of the clamp, and subtracted on the other; we can either determine by simple inspection which this should be, or else follow (with careful regard to the algebraic signs, the annexed

Rule: For collimation constant, clamp east,—

When (R. A. — t) E — (R. A. — t) W is ±, cE is also ±.

VI. We have now applied to the time of transit the corrections for level,rate and collimation; call this corrected time t', then will (R. A. — t') for each star contain both the error of the time-piece and the azimuth error. Our object is now to eliminate the azimuth error: that is, to find a, and then by means of the factor A apply to each star a farther correction aA, leaving us t'' for the corrected time of transit, when finally (R. A. — t'') will give us the error of the time-piece, or ΔT.

To do this, the observations Clamp E. and Clamp W should be treated separately by the computer because a small instrument is very liable to change in azimuth upon reversal. A value of a is thus determined for each side of the clamp. Either may each "time star" be compared with the azimuth star in turn, and a value for a on that side of the clamp deduced from each separate comparison (the average value being finally adopted); or, what is simpler and amounts to the same thing, an average value of (R. A. — t', for the "time stars," with an average factor A, may be compared with the result by the azimuth star.

Rule to Find A. Take the average (R. A. — t') for the time stars, and from this subtract the value of (R. A. — t') given by the azimuth star. Subtract the factor A of the azimuth star from the average of the factors A of "the time stars." Divide the first of the above results by the second, the quotient will be a for that side of the clamp. Then compute aA for the last correction to the observed time of transit of each star. All this (and in fact every step in the computation) must be done with careful regard to the algebraic signs.

Check: *If the foregoing has been accurately done, the chronometer correction, or (R. A. — t''), as given by the "azimuth star" will be exactly equal to the mean (R. A. — t'') of the "time-star."*

In a similar manner determine a value for a, and resulting azimuth corrections to each star on the other side of the clamp, checking the work as before.

Take the mean result from the stars W. and mean result from the stars E.—(if the collimation error adopted was not far from the truth, these two values will be sensibly the same)—and the mean of these two values will be the required error of the chronometer, or ΔT.

GENERAL NOTES.

(1) The constant c changes sign with reversal: the factor C is positive for every star except one observed *sub-polo*.

(2) A negative valve for a, indicates that the instrument is pointing to the west of south. The factor A is positive for all stars except those between the zenith and the pole.

(3) Any difference between the results for ΔT obtained from the two sides of the clamp is caused by a wrong approximation to c.

Since cC is added on one side, and subtracted on the other any small error in assuming the constant is eliminated in taking the mean ΔT from E. and W. stars. A large error in the approximation would derange the results for a on the two sides (and consequently the results for ΔT), hence if the difference is greater, say, than $0^s.15$, it will be well to repeat the latter part of the computation with a closer value for c.

(4) A difference is to be expected, in small instruments, between aE and aW. It is almost impossible to reverse the transit without disturbing the azimuth, either by jarring the supports, or relieving strain in some part of the instrument.

In computing the mean thread of the first and third stars in the preceding set, it was necessary to use the "equatorial intervals," which were known to be as follows (I being the thread first reached by an equatorial star when clamp was E).

I $= -45^s.22$
II $= -30\ .13$
III $= -15\ .02$
IV $= -00\ .06$
V $= +15\ .03$
VI $= +30\ .17$
VII $= +45\ .24$

[For clamp W. the sign changes.]

These, of course, represent the distance of each thread from the mean thread. Following the formula we have, in the case of ϵ Tauri

$$\frac{-45^s.22 \times 1.058}{6} = -07^s.98$$

the mean of the observed threads being $4^h\ 21^m\ 17^s.30$, we have, mean thread $= 4^h\ 21^m\ 9^s.32$.

Time Observations, San Francisco, Cal., March 5, 1886, p. m. Clock No. 3479. C. B. H.

STAR	ε Tauri.	α Tauri.	α Camel.	ε Aurigæ.	β Eridani.	α Aurigæ.	β Tauri.	966 Groom.
Clamp	E.	E.	E.	E.	W.	W.	W.	W.
Declination	+ 18° 56′	+ 16° 17′	+ 66° 9′	+ 43° 39′	− 5° 14′	+ 45° 53′	+ 28° 31′	+ 74° 58′
Factors. A	+ 0.34	+ 0.38	− 1.18	− 0.14	+ 0.68	− 0.20	+ 0.18	− 2.33
Factors. B	1.00	0.97	2.18	1.37	0.73	1.43	1.11	3.08
Factors. C	1.06	1.04	2.47	1.38	1.01	1.44	1.14	3.86
Levels E. and W.	19.5 21.0		21.5 24.0	27.0 19.5	23.5 25.0		18.0 32.0	18.2 33.2
	22.8 17.6		26.5 19.0	21.5 25.5	18.0 30.8		24.5 25.5	25.0 26.5
	42.3 38.6		48.0 43.0	48.5 45.0	41.5 55.8		42.5 57.5	43.2 59.7
Threads, I	—	47.3	—	56.6	41.2	22.5	25.3	44.8
II	37.6	03.1	—	17.5	56.4	44.2	42 6	43.0
III	53.4	18.9	—	38.0	11.5	05.9	59.5	41.5
IV	09.3	34.5	—	58.9	26.6	27.5	16.8	5 23 40.0
V	25.2	50.2	42 32.0	20.0	41.6	49.0	34.0	38.0
VI	41.1	05.9	43 09.0	40.7	56.8	10.5	50.9	36.2
VII	4 21 57.2	4 29 21.5	4 43 46.3	4 54 01.5	5 02 11.8	5 08 32.2	5 19 08.3	34.3
Mean Thread	4 21 9.32	4 28 34.49	4 41 54.54	4 52 59 03	5 01 26.56	5 07 27.40	5 18 16.77	5 23 39.69
Corrections. Rate.								
Level.								
Collim.								
Azimuth.								
Corrected Mean								
Tabular R. A.	4 21 57.86	4 29 23.05	4 42 44.00	4 53 47.93	5 02 15.06	5 08 16.80	5 19 05.75	5 24 31.34
ΔT.								

Similarly for α Camelopardis we obtain,

$$4^h\,43^m\,09^s.10 - 1^m\,14^s.56 = 4^h\,41^m\,54^s.54.$$

Further we have:

Value 1 div. of level $= 1''.01$.

Inequality of pivots, $p = -1''.17 = -0^s.078$ (a very large value). Hourly rate of clock, $r = +0^s.10$.

The minus sign in the value of p shows that the clamp end is *too large*; this follows from the application of the formulæ given for the determination of pivot inequality (see report of the U. S. Coast and Geodetic Survey 1880, appendix No. 14, page 12).

We are now ready to reduce the time set by means of the preceding rules: first step, correction for *Rate*. Adopting 5^h sidereal (as the middle time) $= M$; we have for ϵ Tauri,

$$T - M = (4^h\,22^m) - (5^h\,00^m) = -0^h\,38^m, \text{ say } -0^h.7$$

Thence, $+0^s.10 \times -0.7 = -0^s.07$, which is the correction for rate to be applied to the time of transit of ϵ Tauri. In a similar manner we form the following corrections:

α Tauri $= -0^s.06$; α Camel. $= -0^s.03$; ϵ Aurigæ $= -0^s.01$; β Eridani $= 0^s.00$; α Aurigæ $= +0^s.01$; β Tauri $= +0^s.03$, and for 966 Groom. $= +0^s.04$.

Correction for Level.—In this example the level error has been determined for nearly every star; for α Tauri and α Aurigæ we may take a proportional value of the constant. [When the instrument is perfectly stable, it is preferable to use a mean value of b for each side of the clamp determined from all the readings taken on that side].

To compute the correction for ϵ Tauri we have

$$\frac{(W + W') - (E + E')}{4} = \frac{38.6 - 42.3}{4} = -0.925$$

$$\frac{d}{15} = 0^s.0673 \qquad -0.925 \times 0^s.0673 = -0^s.062 = b.$$

But from the value for "inequality of pivots," we know that the level will show clamp end too high by $0^s.078$. The clamp end in this case is E, which is *apparently* higher by $0^s.062$: in reality, then, the axis is elevated at the opposite end, and $b' = +0^s.016$. $B = 1.00$, and the level correction for ϵ *Tauri*, $b'B = +0^s.02$.

[The astronomer does not study out this relation between the apparent state of the level, and the "inequality," for the correction to each star observed, but determines a formula, once for all, and thereafter uses that formula without further mental effort. When p is —, we obtain the rule

Clamp West $+ b$ must be numerically diminished,

Clamp East, $+b$ must be numerically increased, and the reverse, when p is $+$.
Thus, for correction to 966 Groom., Clamp W, we have

$$\frac{59.7 - 43.2}{4} = +4.125 \qquad +4.125 \times 0^s.0673 = +0^s.278$$

But $+b$ must be numerically diminished, and $b' = +0^s.200$, and $b'B = +0^s.62$].

The level corrections for all the stars are:—

ε Tauri $= +0^s.02$ α Tauri $= +0^s.02$ α Camel. $= -0^s.01$
ε Aurigæ $= +0.03$ β Eridani $= +0.12$ α Aurigæ $= +0^s.24$
β Tauri $= +0.19$ 966 Groom. $= +0.62$

Correction for Collimation.—The mean thread corrected for the two preceding errors we have called t. We now take out R. A. — t for each "time-star".

Clamp E.		Clamp W.	
R. A. $- t = +48^s.59$	$C = 1.06$	R. A. $- t = +48^s.38$	$C = 1.01$
$+48.60$	1.04	$+49.15$	1.44
$+48.88$	1.38	$+48.76$	1.14
Mean $= +48.69$	1.16	Mean $= +48.77$	1.20

Then by the rule:

$$\frac{(+48^s.69) - (+48^s.77)}{1.16 + 1.20} = \frac{-0^s.08}{2.36} = -0^s.034$$

which is the resulting assumption for c on the east side (on the west side the sign of c is changed to $+$). The convenience in multiplying, and bearing in mind No. (3) of the "general notes," alone, we will assume $cE = -0^s.05$; and $cW = +0^s.05$.

From these we obtain the provisional collimation corrections which follow:—

ε Tauri $= -0^s.05$ α Tauri $= -0^s.05$ α Camel. $= -0^s.12$
ε Aurigæ $= -0.07$ β Eridani $= +0.05$ α Aurigæ $= +0.07$
β Tauri $= +0.06$ 966 Groom. $= +0.19$

[The correction for "diurnal aberration," usually included with the collimation constant, has been neglected.]

Correction for Azimuth—Having applied the corrections so far determined to the mean thread we form the annexed table:

Clamp......	B	E	B	E	W	W	W	W
Star..........	ε Tauri	α Tauri	(α Camel)	ε Aurig.	β Erid.	α Aurig.	β Tauri	(966 Gr.)
A..............	+ 0.34	+ 0.38	− 1.18	− 0.14	+ 0.68	− 0.20	+ 0.18	− 2.33
t'..........	09.22	34.40	54.38	58.98	26.73	27.72	17.05	40.34
R. A..........	57.86	23.05	44.00	47.93	15.06	16.80	05.75	31.34
(R. A. $-t'$)	+ 48.64	+ 48.65	(+ 49 62)	+ 48.95	+ 48.33	+ 49.08	+ 48.70	(+ 50.80)

Then to find *a* for clamp East:

$$\frac{+48.64+48.65+48.95}{3}=+48^{s}.747$$

$$=\text{average (R. A.} - t'\text{) of time stars.}$$

$$\frac{+.34+.38+(-.14)}{3}=+0.193$$

$$=\text{average } A \text{ of time stars,}$$

and,

$$\frac{+48.747-49.62}{+.193-(-1.18)}=\frac{-0.873}{+1.373}=-0^{s}.636, \text{ or } a \text{ for clamp E.}$$

In like manner we find a, clamp W., $= -0^{s}.822$.

Multiplying the constant, a, on each side by the factors, A, for each star on that side, we are enabled to apply the remaining correction with the following results for $\varDelta T$:—

Clamp E.

$$(\text{R. A.} - t''),\ \left.\begin{array}{ll} \varepsilon \text{ Tauri} & =+48^{s}.86 \\ \alpha \text{ Tauri} & =+48\ .89 \\ (\alpha \text{ Camel} & =+48\ .87) \\ \varepsilon \text{ Aurigæ} & =+48\ .86 \end{array}\right\} \quad \begin{array}{ll} \multicolumn{2}{c}{\text{Check:}} \\ \text{Time-stars} & =+48^{s}.87 \\ \text{Azimuth-star} & =+48\ .87 \end{array}$$

Clamp W.

$$(\text{R. A.} - t''),\ \left.\begin{array}{ll} \beta \text{ Eridani} & =+48.89 \\ \alpha \text{ Aurigæ} & =+48.92 \\ \beta \text{ Tauri} & =+48.85 \\ (966 \text{ Groom.} & =+48.88) \end{array}\right\} \quad \begin{array}{ll} \multicolumn{2}{c}{\text{Check:}} \\ \text{Time stars} & =+48^{s}.89 \\ \text{Azimuth star} & =+48\ .88. \end{array}$$

The mean of E. and W. gives us for the correction to the timepiece at 5^{h} sidereal or $\varDelta T$, $= +0^{m}\ 48^{s}.88$, (*i. e.*, it is *slow* that much). The results from each side are so nearly the same that there is no need of any repetition (with an improved value of c), and this computation may be considered final.

In very few cases will it be necessary to repeat the computation unless there should be a large difference between the average declinations of the time-stars used in the two sides, or unless the instrument greatly changed its azimuth in reversing.

The successive steps in this process are tedious in detail, but the method of reduction once learned is very simple in practice. The complete reduction of a set of observations like the preceding need not consume over twenty minutes, or half an hour, when the night's record has been fairly completed and the star factors entered. A rigorous reduction of the same observations, by the method of least squares, will give identical results.

I can claim no originality whatever for the method of reduction herewith presented. It is due, I believe, to the Computing Division of the U. S. Coast and Geodetic Survey. The method of successive approximations (one freqently used in astronomical reductions) may appear at first sight like "forcing" the results; but it is perfectly legitimate to adopt such values for the instrumental constants as will best satisfy the observations.

SAN FRANCISCO, CAL., January, 1893.

ASTRO-PHYSICS.

THE WORK OF KAYSER AND RUNGE ON THE SPECTRA OF THE ELEMENTS.*

JOSEPH SWEETMAN AMES.

In a series of papers†, appearing at intervals of about a year, and beginning in 1888, Kayser and Runge, professors of Physics and Mathematics, respectively, in the Hochschule in Hannover, have published the results of a most elaborate and interesting investigation of the spectra of the elements. The work is by no means completed yet, but the results so far attained are most worthy of attention.

They began their investigation from the desire to study the regularities of the various known spectra: the systematic distribution of lines in any one spectrum and the points of resemblance between the spectra of different elements. Many physicists and chemists had investigated both these subjects before; some particular laws had been discovered, but no general relations. The spectra, which even at first sight are open to simple mathematical study, are of two kinds: fluted or banded ones like those of carbon or air; and those containing series of lines which have similar physical properties and which are so distributed as to almost obviously belong together. Liveing and Dewar had called attention to many spectra of this second kind, including those of lithium, zinc and others. The law of arrangement of lines in the fluted spectra was discovered at about the same time by several people, but the first to announce it was Deslandres. It is

$$\frac{1}{\lambda} = a + bn^2; \qquad n = 0, 1, 2, 3, \text{etc.}$$

Stated in words, the second differences of the wave-frequencies are constant for a given band. This formula agrees fairly well with even the latest and best measurements. Deslandres also announced a law connecting the different bands in the same spectrum; and, although it does not seem to be verified by the results of Kayser and Runge, yet it may serve to decide in which group of bands a doubtful one belongs. It was not until 1885 that any simple mathematical formula was found which would express the arrangement of the lines in a spectrum of the second

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* Communicated by the author.

† Ueber die Spectren der Elemente von H. Kayser und C. Runge, Berlin, 1888-1892.

kind. But in that year Balmer published the following empirical formula for the line spectrum of hydrogen,

$$\lambda = \lambda_0 \frac{n^2}{n^2 - 4}; \qquad n = 3, 4, 5, \text{etc.}$$

This formula agrees wonderfully with the results of experiment. There is such a marked resemblance between all the spectra of the second kind that Kayser and Runge proposed applying a slight extension of Balmer's formula to them. Several modifications, such as

$$\frac{1}{\lambda} = A + Bn^{-1} + Cn^{-2}$$

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$$

were tried. To test these, most accurate measurements of the wave-lengths were needed. A careful comparison of the results of previous investigators showed at once such discrepancies and uncertainties that it was decided to make a new determination of the wave-lengths of the spectra of as many of the elements as possible.

Various plans were discussed and tried, and the method finally adopted was that of Rowland, a concave grating mounted with fixed slit. The spectra were produced in general by an arc-light whose carbon poles were bored and filled with some salt of the element under consideration. One great advantage thus secured is that the results obtained are to a certain degree comparable as to temperature and other conditions. The spectrum of iron was chosen as the standard one, with which all others were to be compared, and the wave-lengths of its lines were determined by a series of measurements, made under various conditions, Bell's final value of the *D* lines being accepted as correct. Hence, Kayser and Runge's observations can be at once compared with Rowland's for their scales are identical. The spectra of other elements were then photographed on the same plate with corresponding portions of the iron spectrum, and the wave-lengths of the lines could then be determined by interpolation. All these final measurements were made on a dividing engine which had been specially constructed for the purpose; and the observations were then reduced by the method of least squares.

Since the spectra of carbon and its impurities must, owing to the nature of the process, appear on all the plates, the first step in the enormous undertaking was to determine the lines of the carbon spectrum itself. It consists, as is well known, of a number

[illegible]

[illegible]

[illegible] spectrum [illegible] the [illegible] the earth.

[illegible]

[illegible] determined for [illegible] the series of the [illegible] spectrum [illegible] series each distinguished by the [illegible] Kayser and Runge describe [illegible] the main series whose lines are sharp, [illegible] subsidiary series, whose lines [illegible] the second subsidiary [illegible] and never [illegible] the main series is [illegible] the subsidiary lines are [illegible] temperatures.

[illegible] lithium, sodium, potassium, [illegible] series and all except lithium [illegible] appearing in pairs, i. e., each [illegible] having another associated with it. The subsidiary series of sodium and potassium also are composed of pairs. Copper and silver have the two subsidiary series, also made up of pairs; while gold has no series; but each of the three possess in the ultra-violet an isolated pair, the strongest lines in the spectrum of each. In the second column of Mendelejeff's table the elements arrange themselves from a spectroscopic standpoint into two groups: magnesium, calcium and strontium; zinc, cadmium and mercury. Each of these elements has only the two subsidiary series, made up now of triplets. Further, zinc, cadmium and mercury, each, has in the ultra-violet, as the strongest line in its spectrum, an isolated single line, thus showing an analogy to copper, silver and gold. Magnesium also has a single isolated line, being connected thus with zinc and cadmium, as was to be expected from its chemical properties. Barium has no series.

Of the other elements only aluminium, indium, and thalium have been carefully studied. Each of them has the two subsidiary series, made up of pairs; and for any one element the two series seem to end at almost the same point.

In any one of the subsidiary series made up of pairs or triplets, the differences between the wave frequencies of the members of the pairs is fairly constant; and, if we follow any one series through the spectra of the same group, there is a general connection between this characteristic difference and the atomic weight of the element.

There are certain peculiarities to be noted, common to all the series of any one group. If we observe the formulas

$$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$$

which represent any one series in the different elements, *e. g.*, the first subsidiary; it is noticed that as the atomic weight increases A decreases, *i. e.*, the series are shifted toward the red end of the spectrum. B, on the other hand, remains practically unchanged. As we pass from the elements in the first of Mendelejeff's columns to the higher ones, it is noticed that A increases, *i. e.*, corresponding series recede towards the ultra-violet; while B changes only a little. This shifting of the series may account in part for the vanishing of some of the series in certain of the elements.

It was not to be expected, nor was it observed, that in all cases all the lines of any one spectrum form members of series. In general the larger proportion of the lines seem to be distributed entirely arbitrarily. Kayser and Runge note a most interesting connection between the melting-point of an element and the ratio which the number of series-forming lines bears to the whole number of lines in its spectrum. The higher the melting-point the less as a rule is this ratio. For instance, barium, with its high melting-point, has no series; while lithium, sodium and several other elements, which have low melting-points have all their lines distributed in series. The explanation given by Kayser and Runge is a natural one. The presence of a series in the spectrum of an element shows that the molecule is vibrating in some natural, unconstrained way; and this state can be reached only at temperatures far above the melting-point. Hence, at the temperature of the arc, we should expect series only in those elements which melt at low temperatures. Kayser and Runge think that the main difference between the arc and the spark-spectra is one of temperature; and it is to be hoped that this question will soon be settled. In their last paper (1892) Kayser and Runge describe the results of an investigation of the cause of the apparent stopping of all spectra at about w. l. 2000. They show quite conclusively that this is due, not to absorption by the air or by the grating, but to the action of the grained structure of the photographic films. Herr Schumann of Leipzig is said to have overcome this difficulty, and to be able to photograph as far as w. l. 1000. But unfortunately, he has not published an account of his method.

In commenting upon this work of Kayser and Runge, so far as published, nothing but praise is their due. A higher degree of accuracy has been reached than ever before; most interesting relations have been shown to exist between the lines of any one spectrum, and between the spectra of different elements; credit has been bestowed upon all other investigators; and most complete descriptions of apparatus and methods are given. It is possible that too much importance is laid upon the exactness of the mathematical relations to be expected, but this is not offered as a criticism. One misses a full consideration of certain questions, such as the presence of an element in the Sun, the cause of the anomalous difference in intensity between a line produced in the arc and the corresponding solar line, *e. g.*, some of the calcium lines; but these may well be regarded as beyond the limits which Kayser and Runge have set to their investigations. It is most earnestly to be hoped that their work will continue without any serious hindrance, and be extended to rarer elements, especially to the so-called "rare-earths."

ON THE REFRACTION OF RAYS OF GREAT WAVE-LENGTH IN ROCK-SALT, SYLVITE AND FLUORITE.*

H. RUBENS AND BENJAMIN W. SNOW.

In the 40th Vol. of Wiedemann's Annalen one of the present authors recently described a method whereby a knowledge of the dispersion of rays in the infra-red may be easily obtained. With the aid of this device, the dependence of the index of refraction upon the wave-length was determined for 16 materials, viz.: for 9 different samples of glass, for water, carbon-di-sulphide, xylol, benzol, quartz, rock-salt and fluorite. Inasmuch as in this paper a minute description is given of the methods employed, it will suffice here briefly to refer to the main features of the method of procedure followed in the present determination.

The rays from the zirconia burner of Linnemann, after being reflected from the front and the rear surfaces of a thin plate of air enclosed between two parallel glass planes, were then concentrated upon the slit of a spectrometer, by which means two beams of light were produced capable of mutual interference, so that the otherwise continuous spectrum of the incandescent zirconia plate was crossed by a series of vertical interference bands. The wave-length λ of each such dark band, multiplied by a certain whole number m, always equals the product of twice the thickness d of the layer of air and the cosine of the angle of incidence i of the rays. With the aid of the Fraunhofer lines, the wave-lengths of the interference bands were determined for the visible portion of the spectrum, and from this data were calculated the order m of each dark band and the product $K = 2d \cos i$. The knowledge of these two constants proved then sufficient to determine also the wave-lengths of the interference bands in the infra-red. The positions of these latter were obtained by allowing the sensitive filament of a linear bolometer to wander through the spectrum, and plotting the observed galvanometer deflections as a function of the angular deviation. The interference bands were then recognized as minima or maxima in the curve. In this way, for a series of angular deviations may be obtained the corresponding indices of refraction, that is a number of points in the $n - \lambda$ plane may be determined, which, when joined by a smooth curve, give the curve of dispersion for the material examined.

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* Communicated by the authors. Translated from Wiedemann's Annalen, Vol. 46, 1892.

In the majority of the bodies thus investigated, the limit of the region of the infra-red capable of being explored was prescribed by the absorption which increases rapidly with increasing wave-length. In two cases alone, viz.: when working with rock-salt and with fluorite did we discontinue the observations at wave-lengths $\lambda = 5.7\mu$ and $\lambda = 3.3\mu$ respectively before the region of strong absorption was reached. This was rendered necessary by the fact that the apparatus employed proved to be insufficiently sensitive to measure the exceedingly feeble energy found in the spectrum of the zirconia burner at these long wave-lengths.

As a means of continuing the investigation beyond this point, two ways of improvement suggested themselves. At first we thought it possible to increase the energy of the source of light, but all endeavors to attain this end proved of no avail. The use of the electric arc for this purpose, after a short but thorough trial, was discontinued. Even arc lamps of unusually good regulation, when supplied by the almost perfectly constant current of the Berlin central station, gave a radiation too fluctuating to be used in place of the zirconia light. The regulation of the arc by hand was also tried, but likewise without success. The use, moreover, of a zirconia burner of nearly double the dimensions of the former resulted in only a feeble increase in the energy, while a series of new difficulties was thereby introduced, such as the melting of the platinum cell, a greater consumption of gas, etc. We concluded, therefore, for the further investigations, to retain the source of light in its original form, and to make better use of the energy here at hand by increasing as far as possible the sensitiveness of the measuring apparatus.

The first change toward the accomplishment of this end was effected in the substitution of two plane surfaces of larger dimensions in place of the reflecting plates formerly used. For this purpose the optical firm of Carl Zeis, of Jena, most generously provided us with two plates with plane surfaces 4 cm. square and 1 cm. thick, one of crown glass and the other of fluorite. The plates were set in metal frames, and the distance between them regulated by a system of screws, as in the former case. With the exception of the extreme edges, both plates were ground to a truly plane surface. A rectangular opening in a diaphragm placed in the path of the rays allowed only that light to enter the slit of the spectroscope which had been reflected from the central portion of the plates. The interference bands thus produced were unusually sharp, as can be seen from the pronounced minima of the curves in Figs. 1, 2 and 3, which represent the three different energy spectra. Hardly need it be mentioned that in the following experiments the entire optical system consisted entirely of rock-salt and fluorite.

The delicacy of the bolometer was increased chiefly by using a galvanometer of the highest degree of sensitiveness, which one of us had constructed, and which has been described in detail in a recent paper.[*] The coils of the galvanometer, when in series, amounted in resistance to 140 ohms; and when the period of the needle was reduced for the single swing to 10 seconds, 1 mm. deflection on the scale indicated a current of 1.3×10^{-11} ampère. With this degree of astaticism the zero point of the needle was perfectly constant. The bolometer with which the following determinations were made is described in the previous paper as No. 2. It consisted of two strips of platinum 12 mm. long and $\frac{1}{12}$ mm. wide, each having about 80 ohms resistance, only one of these being exposed to radiation. With the aid of the new galvanometer we were able to reach a sensitiveness of 0.000003° C. per mm. deflection. A standard candle one meter distant produced a deflection of 400 mm.

With the exception of the changes here mentioned, all pieces of apparatus were identical with those formerly described. The relative positions, moreover, of the instruments, as well as the manner and the order in which the operations were made, were retained unchanged. We can, therefore, pass at once to the results of our observations.

Measurements were made upon three materials well known for their diathermous properties, rock-salt, sylvite and fluorite.

I ROCK-SALT.

We had at our disposal a prism of this mineral having a triangular base 3½ cm. on each side and 4½ cm. in height. Before being used, the prism was freshly polished and its refracting angle redetermined. The observations with the bolometer gave the energy spectrum represented in Fig. 1. The positions of the maxima and the minima were corrected, as in the paper cited above, with the aid of the enveloping curve whereby the points of contact of the two curves were used without further modification as the characteristic points in question. As the theory shows, this method gives a closer approximation to the quantities required than the method by construction given in the former paper. But little weight, however, is to be attached to the su-

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[*] Benjamin W. Snow, Wied. Ann., Vol. 47, p. 216, 1892.

periority of this modification, as both methods lead to results which are identical to the fourth decimal place.

Inasmuch as the present investigation was undertaken expressly for the purpose of extending measurements as far as possible in the infra-red, we were compelled to use a comparatively thick layer of air for reflecting the interfering beams of light, which brought the interference bands in the spectrum very near together. It was, however, quickly found that even the narrow width of the bolometer and the impurity of the spectrum, caused by the aberration of the lenses, placed a limit beyond which the further reduction of the breadth of the interference bands could not be carried. With the feeble dispersion of the materials used, this limit was practically reached when the visible spectrum was crossed by seven or eight interference bands, which gave a value to the constant $K = 2d \cos i$ of about 8.5μ. According to this, the minimum of the first order, which is the farthest possible allowable point in the infra-red, has the wave-length $\lambda = 8.5\mu$. Then follow the maximum of the second order, and the corresponding minimum, which have wave-lengths $\lambda = 5.7\mu$ and 4.3μ respectively. Although the curvature of the curve of dispersion in this region is slight, it seemed to us nevertheless desirable to add for greater accuracy in our measurements other possible points to the small number already obtained. In order to attain this end, we found it advantageous to use not only the corrected positions of the maxima and minima and the corresponding wave-lengths for plotting the curve of dispersion, but also the points of intersection of the energy curve, $G = f(\alpha)$ (see Fig. 1), with the curve of mean energy, $R = f(\alpha)$, since the wave-lengths corresponding to the abscissæ of these points are easily calculated. This latter curve might have been observed, directly had the distance between the plates enclosing the reflecting layer of air been sufficiently increased.

This curve, $R = f(\alpha)$, which expresses the distribution of energy when no interference is present, can be constructed, however, with sufficient accuracy, when at each point an ordinate is erected equal to the mean of the ordinates of the corresponding points in the envelopes P and Q. If the curve $G = f(\alpha)$ is intersected at any point by the curve $R = f(\alpha)$, then the amplitude for the abscissa of this point must have the same magnitude which it would have attained had a superposition of the energy of the two beams taken place without interference.

The vibratory motion of the two beams whose amplitude and period are A and T respectively, may be represented by the equation:

$$y_1 = A \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

$$y_2 = A \sin 2\pi\left(\frac{t}{T} - \frac{x+K+\frac{\lambda}{2}}{\lambda}\right)$$

They unite to form the ray:

$$Y = 2A \cos\frac{\pi\left(K+\frac{\lambda}{2}\right)}{\lambda} \sin 2\pi\left(\frac{t}{T} - \frac{x+\frac{K}{2}+\frac{\lambda}{4}}{\lambda}\right)$$

$$= 2A \sin\frac{\pi K}{\lambda} \sin 2\pi\left(\frac{t}{T} - \frac{x+\frac{K}{2}+\frac{\lambda}{4}}{\lambda}\right)$$

It follows from what has been said above that for the abscissa of the point of intersection of the two curves, R and G, the amplitude of the beam Y, viz.: $2A \sin\frac{\pi K}{\lambda}$, must equal $\pm A\sqrt{2}$. λ is accordingly determined from the equation

$$\sin\frac{\pi K}{\lambda} = \pm \tfrac{1}{2}\sqrt{2}.$$

$$\frac{\pi K}{\lambda} = \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4} \ldots \frac{(2n+1)\pi}{4}$$

where n is any whole number. The wave-length, therefore, of each point of intersection is given by the equation:

$$\lambda = \frac{4K}{2n+1}.$$

A knowledge of the order of the adjacent maxima and minima gives at once an interpretation to the quantity n. If the point of intersection in question lies in such a way that the adjacent minimum (mth order) lies on the side of the longer wave-lengths and the adjacent maximum on the side of the shorter wave-lengths, then $n = 2m$.

The introduction of these points in the calculation of the curve of dispersion made it possible for us to conduct the observations with interference bands as broad as were necessary, and at the same time to obtain a sufficiently great number of points to enable us to ascertain the character of the curve of dispersion in the extreme infra-red with nearly the same degree of accuracy as in those portions of the spectrum lying but little beyond the reach of the eye.

At this point mention should be made of a peculiarity of the energy curve which may be observed in the drawing (Fig. 1). The deflections of the galvanometer, at the point of the last minimum a_{11}, not only sink to zero, but even assume negative values. The cause of this singularity, which also appears to a smaller degree in the energy curve of fluorite, is to be found in the fact that the second, unilluminated arm of the bolometer, which was placed in the apparatus within a casing of hard rubber, received upon its surface, notwithstanding this covering, a greater amount of energy than the first arm, which was exposed to the direct radiation. The plausibility of this explanation is increased when we remember that the covered resistance is then at a portion of the spectrum in which the mean energy is 50 times greater than in the neighborhood of the minimum a_{11}, and that ebonite is not opaque to thermal radiations of great wave-length.

In the following table are found the results of the observed indices of refraction and wave-lengths. The first column entitled "Name," gives the quality of the characteristic point in question, as Fraunhofer line, minimum (a), maximum (b), or point (c) of intersection of the curves G and R; the second column contains the angle of deviation α, as measured on the graduated circle; the third contains the index of refraction n, calculated from the refracting angle φ and the angle of deviation α according to the formula

$$n = \frac{\sin \frac{\varphi + \alpha}{2}}{\sin \frac{\varphi}{2}};$$

the fourth column contains finally the wave-length, which is calculated from the order m of the interference band and the constant $K = 2d \cos i$. The curve of dispersion plotted from the data of this table is found in Fig. 4*a*.

TABLE I.

Refracting Angle of the Rock-salt Prism. $\varphi = 60^\circ\ 2'$;
$K = 8.307\mu$; a_1 *is the 11th order.*

Name	α		n	λ	Name	α		n	λ
	°	′				°	′		
H_γ	42	37	1,5607	0,434$^\mu$	b_3	40	2½	1,5321	0,978$^\mu$
F	41	56	1,5531	0,485"	a_4	39	58	1,5313	1,035"
D		7	1,5441	0,589"	b_4		54½	1,5305	1,107"
C	40	47	1,5404	0,656"	a_5		51	1,5299	1,186"
a_1		29	1,5370	0,755"	b_5		47½	1,5293	1,277"
b_1		22½	1,5358	0,790"	a_6		44	1,5286	1,384"
a_2		16½	1,5347	0,831"	b_6	39	41	1,5280	1,511"
b_2		11½	1,5337	0,876"	a_7		38	1,5275	1,660"
a_3		7	1,5329	0,923"	b_7		35	1,5270	1,845"

TABLE I—*Continued.*

Name	α		n	λ	Name	α		n	λ
	°	′				°	′		
a_8	39	32	1,5264	2,076μ	a_{10}	39	2	1,5208	4,150μ
b_8		28	1,5257	2,372"	c_3	38	56	1,5197	4,745"
a_9		22½	1,5247	2,771"	b_{10}		49	1,5184	5,540"
c_1		18	1,5239	3,022"	c_4		37½	1,5163	6,647"
b_9		13½	1,5230	3,320"	a_{11}		24	1,5138	8,307"
c_2		7	1,5217	3,690"					

It is well known that Professor Langley,* by a method wholly different from the one here described was able to follow the dispersion in rock-salt to a wave-length $\lambda = 5.3\ \mu$. He found in these experiments that the curve of dispersion from about $\lambda = 2\ \mu$ on followed very nearly a straight line. Owing to the fact that even with the elaborate means at hand he was unable to extend measurements by his method further than this in the direction of the long wave-lengths, he concluded to extend this straight line throughout the still more distant region of the infra-red in which his observations were taken. Many theoretical objections are at once suggested by so extensive an exterpolation. Among these criticisms may be mentioned one in particular, that from a definite wave length on, the indices of refraction would assume negative values, which at once points to an utter impossibility. There remained, however, the possibility that, within the limits of Professor Langley's measurements of energy, the straight line exterpolation gave results which were at least a first approximation to the true value. A glance at curve, Fig. 4*a* shows, on the other hand, that in reality this is not the case. Indeed it is true that our own curve of dispersion tends toward a straight line until a point is reached almost as distant as $\lambda = 5\ \mu$; but at $\lambda = 5\ \mu$ the curve begins gradually to lessen its inclination to the horizontal axis of wave lengths, and at $\lambda = 8\ \mu$ the effect of this curvature is so considerable that a straight line exterpolation from $\lambda = 5\ \mu$ on to this point would introduce an error in the determination of wave-length not less than 1μ.

In the following table a comparison is made between our results and those of Professor Langley. It is to be noticed that his curve, so far as this is plotted from his observations, agrees fairly well with our own, but that his values obtained by exterpolation differ widely from those observed by us, and that this difference increases as the wave-length becomes longer. There is also added here for completeness the data obtained from the previous paper. That an easier comparison may be made with Langley's figures, the wave-lengths selected increase by multiples of $\lambda_D = 0.589\mu$.

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* Langley, Ann. de Chim. et de Phys. (6) 9, p. 433, 1886.

TABLE II.

Wave-Length	*n* (Langley)		*n* (Rubens)	*n* (Rubens & Snow)	*n* (Langley) — *n* (Rub. & Sn.)
1 $\lambda_D = 0{,}589^{\mu}$	1,5442	Observed	1,5441	1,5441	0,0001
2 $\lambda_D = 1{,}178$"	1,5301		1,5300	1,5301	0
3 $\lambda_D = 1{,}767$"	1,5272		1,5269	1,5272	0
4 $\lambda_D = 2{,}356$"	1,5254		1,5253	1,5256	— 0,0002
5 $\lambda_D = 2{,}945$"	1,5243		1,5241	1,5240	+ 0,0003
6 $\lambda_D = 3{,}534$"	1,5227		1,5227	1,5226	1
7 $\lambda_D = 4{,}123$"	1,5215		1,5214	1,5212	3
8 $\lambda_D = 4{,}712$"	1,5201		1,5202	1,5200	1
9 $\lambda_D = 5{,}301$"	1,5186		1,5189	1,5188	— 0,0002
10 $\lambda_D = 5{,}890$"	1,5172	Extrapolated	—	1,5177	5
11 $\lambda_D = 6{,}480$"	1,5158		—	1,5167	8
12 $\lambda_D = 7{,}070$"	1,5144		—	1,5158	13
13 $\lambda_D = 7{,}66$ "	1,5129		—	1,5146	19
14 $\lambda_D = 8{,}25$ "	1,5115		—	1,5138	23

The values, therefore, attributed by Professor Langley* to the wave-lengths in that region of the spectrum lying between $\lambda = 0$ and $\lambda = 5\mu$ are undoubtedly correct. Beyond this limit, however, at least as far as $\lambda = 8.3\mu$, the values assumed are too small, but it is not impossible that when still greater wave-lengths are reached the sign of the error may change. The results, nevertheless, of his observations remain of the greatest interest, since it will be easily possible to apply a correction to the wave-lengths, as soon as the dispersion in rock-salt can be followed to sufficiently small indices of refraction.

SYLVITE.

The behaviour of rock-salt is in every respect similar to that of the mineral sylvite, to which it stands in close chemical relation. There was placed at our disposal a prism of this material 14 mm. at the base and 20 mm. in height, whose surfaces were so well polished that the refracting angle could be determined to within 0.5 minutes.

In Fig. 2, the observed galvanometer deflections are plotted as a function of the angular deviation of the bolometer arm. From this curve is computed the table of dispersion in the manner described above. Corresponding to this is plotted the curve of dispersion Fig. 4^b:

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* Langley, Sill. Jour. (3) 31, p. 1-12. 1886, further (3), 32, p. 83-106, 1886 and (3), 38, p. 421-440. Phil. Mag. 26, p. 505, 1888. The same is true of the papers of Angström, Öfversigt af Kongl. Vet. Akad. Förhandl. 9, p. 549, 1889, and 7, p. 331, 1890, and W. H. Julius, Arch. Néerl, p. 310-384, 1888.

TABLE III.

Refracting Angle of the Sylvite Prism $\varphi = 59° 54'$.
$K = 8.022\mu$; a_1 is 10th order.

Name	α		n	λ	Name	α		n	λ
H_γ	37	30	1.5048	0.434 μ	b_5	35	5	1.4766	1.458 μ
F	36	55	1.4981	0.486 "	a_6		2½	1.4761	1.603 "
D		13½	1.4900	0.589 "	b_6	34	59½	1.4755	1.781 "
C	35	57	1.4868	0.656 "	a_7		56½	1.4749	2.005 "
a_1		37	1.4829	0.802 "	b_7		53	1.4742	2.291 "
b_1		32	1.4819	0.845 "	a_8		48	1.4732	2.673 "
a_2		27	1.4809	0.893 "	b_8		43	1.4722	3.209 "
b_2		23½	1.4802	0.944 "	c_1		40½	1.4717	3.561 "
a_3		20	1.4795	1.003 "	a_9		38	1.4712	4.011 "
b_3		16½	1.4789	1.070 "	c_2		35½	1.4708	4.577 "
a_4		13	1.4782	1.145 "	b_9		32	1.4701	5.345 "
b_4		10	1.4776	1.234 "	c_3		28	1.4693	6.412 "
a_5		7½	1.4771	1.337 "	a_{10}		22	1.4681	8.022 "

A study of this curve shows that the dispersion in sylvite which in the visible spectrum is only slightly inferior to that in rock-salt decreases in a similar manner but far more rapidly than in this latter mineral, so that at wave-length $\lambda = 8\mu$ its dispersion is only about one third part of the corresponding dispersion in rock-salt. Notwithstanding the great durability of this material and its permanence in moist air, as well as its almost perfect transparency to thermal radiations, the exceedingly rapid decrease in the dispersive power of sylvite renders this substance not so well adapted for experiments involving the use of prisms as rock-salt, whose surfaces are only with difficulty kept perfect. In the construction of condensing lenses this difficulty does not occur.

FLUORITE.

The prism here examined is the same one which was used in the former investigation. The value of the refracting angle was determined anew, and was found to agree very closely with the observations previously made.

For a long time we tried in vain to measure the energy spectrum produced by the fluorite prism beyond wave-length $\lambda = 3.5\mu$. The results of the previous investigation show the cause of our failure to be due to the fact that after a region of comparative feeble dispersion, the dispersive power of fluorite increases and the energy in this part of the spectrum becomes proportionally weaker. In order to make further advances, we were finally compelled to open wider the slit of the spectrometer at those places where the radiant energy sinks below a measurable quantity. The repetition of this device enabled us to reach a wave-length in the infra-red greater than $\lambda = 8\mu$. In the curve shown in Fig. 3, which represents the observed distribution of energy produced by the fluorite prism, the slit was twice opened, the first time from 0.1 mm. to 0.4 mm. when the arm of the bolometer was at a deviation $\alpha = 30° 10'$, and a second time from 0.4 mm. to 1.0 mm. at the angle of deviation of $\alpha = 28° 50'$. By this means the deflections of the galvanometer were increased four fold and ten fold respectively. Owing to the greatly increased dispersion and the corresponding increase in the breadth of the interference bands, this change in the width of the slit did not materially interfere with the sharpness of the bands in this region of the spectrum. Inasmuch as only one side of the slit was movable, a correction had to be applied to the reading of the arm of the bolometer when the slit was opened.

The distribution of energy as shown in Fig. 3 gives a curve whose character is wholly different from the representation of the energy spectra produced by rock-salt or sylvite, given in Figs. 1 and 2. While in the latter, the breadth of the interference bands increases only slowly as the extreme infra-red is reached, amounting finally hardly more than to double the smallest value, the breadth of these bands varies, in the energy curve as given by the fluorite prism, from 5 minutes to more than 2½ degrees. Corresponding to this peculiar characteristic in the energy spectrum of fluorite the quality of the dispersion in this mineral is quite different from that of the material previously considered. In the following table, which contains this data, the indices of refraction are given only to three decimal places. As a result of the very considerable breadth of the interference bands, it is impossible to locate the positions of the characteristic points with the precision attainable in other cases.

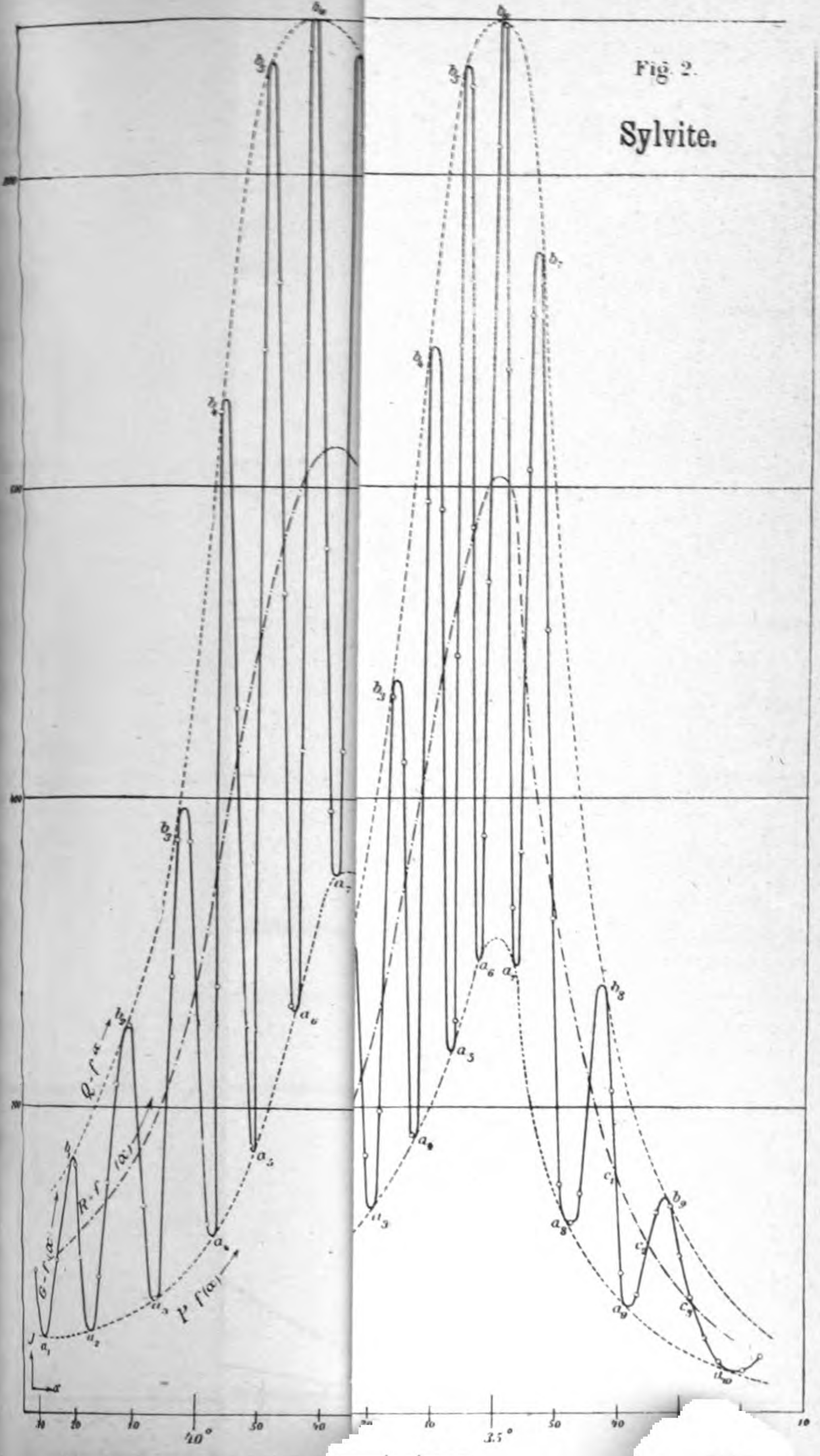
TABLE IV.

Refracting Angle of the Fluorite Prism 59° 59½′.
$K = 8.070\mu$; a_1 is the 10th order.

Name	α		n	λ	Name	α		n	λ
	°	′				°	′		
H_γ	32	5	1,4398	0,434$^{\mu}$	b_5	30	59	1,4267	1,466$^{\mu}$
F	31	52	1,4372	0,485 “	a_6		55½	1,4260	1,613 “
D		36	1,4340	0,589 “	b_6		51	1,4250	1.792 “
C		29	1,4325	0,656 “	a_7		46	1,4240	2,019 “
a_1		19	1,4307	0,807 “	b_7		38	1,4224	2,303 “
b_1		17	1,4303	0,850 “	a_8		29	1,4205	2,689 “
a_2		14½	1,4299	0,896 “	b_8		13	1,4174	3,225 “
b_2		12	1,4294	0,950 “	a_9	29	46	1,4117	4,035 “
a_3		10	1,4290	1,009 “	c_1		29	1,408	4,62 “
b_3		8	1,4286	1,076 “	b_9		4	1,403	5,38 “
a_4		6	1,4281	1,152 “	c_2	28	30	1,396	6,46 “
b_4		4	1,4277	1,240 “	a_{10}	27	5	1,378	8,07 “
a_5		2	1,4272	1,345 “					

Fig. 2.

Sylvite.



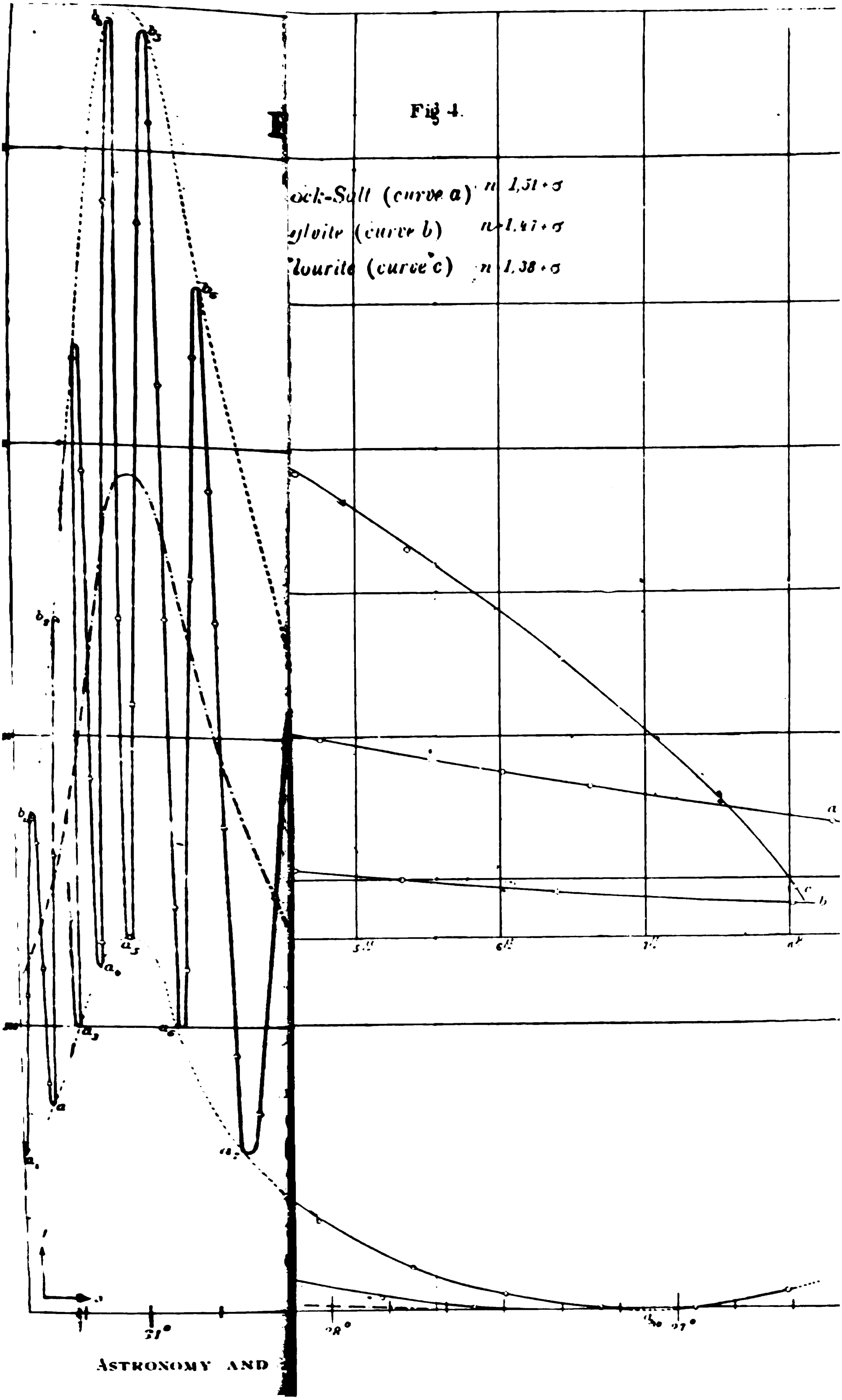
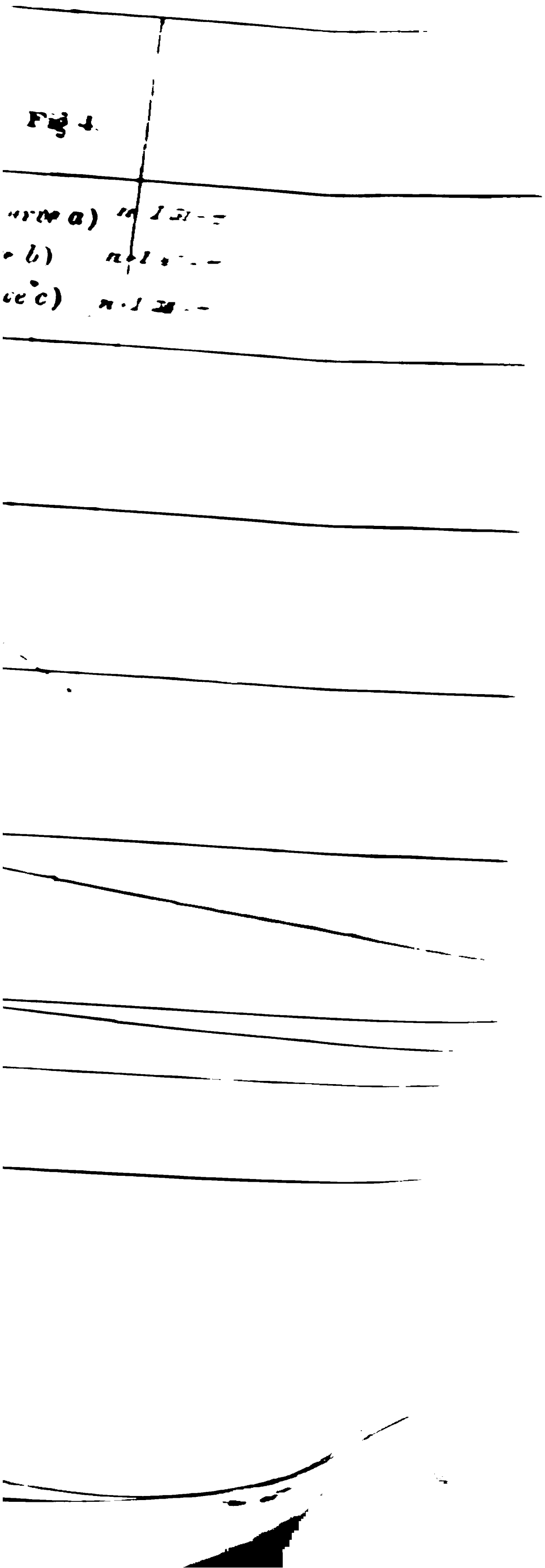


Fig. 4.

ASTRONOMY AND



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The curve of dispersion shown in Fig. 4^c exhibits more graphically than this table the peculiar character of the dispersion. From this it is seen that the dispersive power of fluorite decreases as far as $\lambda = 2\mu$ and then gradually increases reaching at $\lambda = 8\mu$ a value only slightly inferior to the value of the dispersion in the red.

Compared with rock-salt and sylvite, the dispersion of fluorite in the visible spectrum is exceedingly small, and unusually great in the infra-red, so that this material is peculiarly well adapted to the production of prismatic heat spectra, an advantage which is still further increased by the ease with which it can be worked and by the permanence of its surfaces in the air.

Physical Laboratory, University of Berlin,
June, 1892.

THE SPECTROHELIOGRAPH.*

GEORGE E. HALE.

The spectroheliograph is an instrument used in photographing the Sun by monochromatic light. It has been in daily use at the Kenwood Observatory for more than a year, and a collection of fifteen hundred photographs is sufficient evidence of its practical importance. Without entering into a discussion of these results, which have been described and illustrated in previous numbers of Astronomy and Astro-Physics, suffice it to say that the faculæ in the brightest part of the solar disc, as well as the chromosphere and prominences encircling the circumference, are clearly shown and sharply defined in the photographs.

The practicability of the instrument having thus been demonstrated, it may be of interest to examine its construction somewhat in detail, and to point out the advantages aud disadvantages of such modifications of the original design as may seem best adapted for special purposes. Let us first consider, however, certain similar instruments, which, though never successfully employed, are nevertheless of interest and importance in the history of solar photography. These devices were brought to my attention not long after my independent invention of the spectroheliograph in 1889, and have been referred to in several of my papers. In order that the history of solar prominence photography may be complete, methods not embodying the principle of the spectroheliograph will also be described.

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* Communicated by the author.

[illegible]

[illegible] the general [illegible] of the prominences can be seen. This is due partly to a small displacement of the image during the exposure, as the [illegible] was slightly out of adjustment. The [illegible] makes the employment of this line [illegible] in the use of a wide open [illegible] of ordinary size it is generally [illegible] to allow the whole prominence [illegible] the great increase in brilliancy [illegible] the details of structure. On account of [illegible] and the dark absorption bands [illegible] H and K lines are far superior to Hγ for [illegible] photography. A large number of photographs taken [illegible] in [illegible] through the H and K lines by means of a wide slit, [illegible] in many cases showing the forms remarkably [illegible] that this method is of little practical value.

Dr. Carl Braun devised in 1872 an apparatus for photographing the prominences through a narrow moving slit, and published a description of it in *Astronomische Nachrichten*, No. 1899; *Poggendorff's Annalen*, Bd. 148, S. 475, and also in the *Berichte von*

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* *Nature*, Jan. 28, [illegible]. Reprinted from the *Journal of the Franklin Institute*.

dem Haynald'schen Observatorium zu Kalocsa. Upon a large metal plate fastened to the eye-end of an equatorial refractor a modified form of spectroscope is so arranged as to allow a limited motion of rotation, in a plane containing the axes of the collimator and observing telescope, about a pivot situated at the irpoint of intersection. The solar image formed by the equatorial is focussed on a slit at the end of the collimator. Passing out of the collimator the rays fall vertically upon a right-angled prism, which is so ground that for rays falling normally upon the second surface the limit of total reflection corresponds to the index of the prominence line employed (*h* or $H\gamma$). It is thus intended that all rays of greater refrangibility shall be totally reflected, and pass out of the apparatus to one side. The rays of less refrangibility than $H\gamma$ are refracted through the hypotenuse surface, and fall upon the similar surface of a second right-angled prism, which is exactly parallel to the first, and about 0.1 mm. from it. In passing out of this second prism the rays are rendered parallel to their original direction. They then meet a third prism of a slightly obtuse angle, by means of which all rays except those of a refrangibility very nearly equal to that of $H\gamma$ leave the optical system in a diverging bundle. $H\gamma$ with the rays near it are totally reflected, and after passing out of the prism they are brought to a focus by a small observing telescope, thus forming a nearly monochromatic image of the slit. A second slit near this focus cuts out the $H\gamma$ region, and a camera fastened upon the supporting plate enlarges the image 8 or 10 times. In photographing a prominence the clock-work of the equatorial is to keep the solar image motionless, while at the same time by a system of long levers the plate carrying collimator, prisms and telescope is made to turn slowly on the pivot, the stationary camera building up the prominence image upon the sensitive plate.

The idea of building up an image of a prominence by photographing the successive images of a moving slit was possibly suggested to Dr. Braun by the experiments of Professor Young and others in attempting to observe prominence forms with a rapidly oscillating narrow slit.[*] Zöllner's criticism of oscillating slits and rotating spectroscopes, based on experiments made in 1869 on terrestrial light-sources,[†] was substantiated by Professor Young's conclusion that a widely opened slit is best suited for visual observations, and the oscillating slit was never employed

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[*] Described in *Nature* Dec. 28, 1870.

[†] *Astronomische Nachrichten*, No. 1772.

in practice. Dr. Braun seems to have been the first to see that the retina could be very advantageously replaced by the photographic plate.

A careful examination of his proposed apparatus reveals certain points of excellence and some defects. It is safe to say, however, that if it were constructed as described, and used with the Hγ or *h* line and the collodion plates then in vogue, it would not have proved of practical value.

It is indeed doubtful whether any form of apparatus in which either the Hγ or *h* line is employed could be successfully used in photographing the prominences. Images of some sort would probably be obtained, but they would be too feeble for practical purposes. Present success in solar prominence photography is largely due to our employment of the brilliant K line. As compared with K, Hγ and *h* are feeble lines. Almost equally serious is the fact that they lie on a background of bright atmospheric spectrum, while H and K are enclosed in broad dark absorption bands. In practice the second slit of a spectroheliograph cannot be made so narrow as to allow the passage of the prominence line alone. Some of the atmospheric spectrum on either side of the line is also admitted to the photographic plate, where it tends to obscure the image of the prominence. In the case of H and K the dark bands largely do away with this difficulty, as I pointed out in my studies of these lines in 1891. H cannot be used, however, on account of its close companion, the Hε line, and our choice is therefore narrowed down to K.

Dr. Braun's device for producing a monochromatic image of the slit is ingenious, but its entire practicability may be doubted. It would have to be constructed with great accuracy for light of a single wave-length, and its delicacy would interfere with permanency of adjustment. But even under the best of conditions it would hardly succeed in isolating a single line in the spectrum, as Dr. Braun himself remarks: "Man wird es wohl nicht dahin bringen können, dass durch diese Justirungen eine Spectrallinie (Hγ) vollständig isolirt werde; und es wird immer einiges Licht aus der Nachbarschaft dieser Linie auf die Platte gelangen. Doch das schadet nichts; denn die Folge davon ist nur die, dass auch die ganze Sonnenscheibe mit Flecken und Fackeln in einem Kräftigen Bild dargestellt werden wird."* It is true, however, that this additional light, while of advantage in the way pointed out, would make it difficult and perhaps impossible to photograph prominences, for which, it should be remembered, the instrument was primarily designed.

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* *Berichte von dem Hayanldschen Observatorium*, 1886, p. 162.

The paragraph quoted above clearly proves that the idea of photographing the faculæ was a secondary one, and did not involve the belief that any advantage over ordinary methods of photography would result from the use of the $H\gamma$ line.

Another disadvantage of the apparatus is the loss of light when the axis of the collimator makes an angle with the axis of the equatorial. The maximum loss depends upon the diameter of the solar image. It can be obviated by increasing the angular aperture of the collimator.

A difficulty which cannot be avoided with Dr. Braun's apparatus also results from the motion of the slits in a circle. With a large solar image the maximum departure of the slit from the in focal plane of the equatorial would have a very appreciable effect distorting the image.

Further disadvantages are the weight of the moving parts, the method of producing the motion by means of the driving-clock of the equatorial, and the impracticability of constructing the instrument on a large scale.

The advantages of the apparatus are the equality of the angular motion of the two slits, and the consequent small distortion of the solar image.

Another form of the apparatus, in which it was proposed to isolate the $H\gamma$ line in the spectrum formed by two prisms, agreed in all other particulars with the device described above, but was considered by Dr. Braun to be much inferior. Its obvious disadvantage would be the curvature of the lines in the spectrum, and the resulting distortion of the solar image. Neither of the instruments was ever constructed. The projects were first made known tome by Dr. Braun* in reply to a published note on my proposed methods of photographing the prominences.†

In 1874 Dr. Oswald Lohse made several unsuccessful attempts to photograph the chromosphere and prominences by direct methods, *i. e.*, using the direct image of the Sun without a spectroscope. In 1880 he devised a special form of apparatus for the purpose. It consisted of a direct-vision spectroscope held within a large metallic drum, with its axis of collimation parallel to the axis of the telescope to which it was attached. The Sun's image at the focus of the equatorial was made to fall upon a metallic diaphragm exactly equal to it in size, and as the spectroscope was placed eccentrically in the drum, the radial slit received light from the region outside the diaphragm, including, of course, the chromosphere and prominences. The drum was supported in an

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* *Astronomische Nachrichten*, No. 3014. † *Ibid*, No. 3006.

iron frame-work, and was rotated by hand, so that the slit passed over all points on the limb in one complete revolution. A second slit at the focus of the spectroscope allowed only the Hγ line to fall upon a stationary sensitive plate beyond it.*

Dr. Lohse's apparatus was thoroughly tested by a long series of experiments carried on at Potsdam, but it did not prove a success, and the investigation was finally abandoned.

The cause of failure lay not in the principle on which the apparatus was based, but in the means adopted to carry it into effect. The employment of the Hγ line was attended with the disadvantages mentioned above, and these were aggravated by the small dispersion and the illumination of the field by the direct vision prism. Add to these the obvious defects in the mechanical design of the instrument, and the impossibility of producing uniform rotation by hand, and it is easy to account for the lack of success.

In a paper published in 1872, Lockyer and Seabroke proposed to use a ring slit in the following manner for photographing the prominences: "A large Steinheil spectroscope is used, its usual slit being replaced by the ring one. A solar beam is thrown along the axis of the collimator by a heliostat, and the Sun's image is brought to a focus on the ring slit by a 3¾-inch object-glass, the solar image being made to fit the slit by a suitable lens. By this method the image of the chromosphere received on the photographic plate can be obtained of a convenient size, as a telescope of any dimensions may be used for focussing the parallel beam which passes through the prisms on to the plate."† Drawings were exhibited showing prominences observed with the ring slit, but I can find no record that photographs of the chromosphere and prominences were ever obtained in this way. The disadvantages of the method are evidently those of the ordinary open slit already referred to.

In 1879 a letter was published in the *Comptes rendus* describing a method designed by C. W. Zenger to photograph the chromosphere, prominences and corona without the use of a spectroscope. The plate was first put into a solution of pyrogallic acid and citrate of silver, and then given a very short exposure to the direct solar image, using "une couche absorbant tous les rayons dont est composée la lumière de la couronne et des protubérances solaires." The author goes on to add: "C'est en étudiant par le spectroscope des pellicules ainsi obtenues, que j'ai constaté l'ab-

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* *Z. f. Instrumentenkande*, 1, 22.

† *Proceedings Royal Society*, v. 21, p. 105.

sorption de raies caractéristiques de la couronne et des protubérances, et c'est pourquoi les protubérances et la chromosphère, sur les épreuves négatives, apparaissent blanches; la couronne en est moins prononcée, seulement blanchâtre, ce qui montre que la lumière coronale est très-distincte de celles de la chromosphère et des protubérances."* Although M. Zenger declared his readiness to send specimens of his negatives to the Academy, the subject seems to have been dropped, and further details were not made known.

M. Janssen has also tried to use the direct solar image. In a short note on the subject he says: "Il faut que l'action lumineuse solaire s'exerce assez longtemps pour que l'image solaire devienne positive jusqu'aux bords, sans les dépasser. Alors la chromosphère se présente sous forme d'un cercle noir, dont l'épaisseur correspond à 8″ on 10″."† In this case, and also in Zenger's, where a direct image of the Sun is received upon a photographic plate, it is highly improbable that the chromosphere or prominences produce any appreciable effect. The "black circle" is solely due to the photographic action of the brilliant disc of the Sun, and would be formed even if the chromosphere did not exist.‡

Two methods of photographing the chromosphere and prominences were independently devised by the writer in 1889.

(1.) The rate of the driving clock of an equatorial telescope is so altered that the Sun's image moves slowly across the slit of a spectroscope of considerable dispersive power, the direction of the Sun's motion being at right angles to the slit. One of the prominence lines is brought into the center of the field of the observing telescope, where it passes through a narrow slit just within the focus, and falls upon a photographic plate. The plate is moved at right angles to the spectral lines at a velocity depending upon that of the Sun's image.

(2.) The solar image is kept stationary by the driving clock of the equatorial, and the slit of an attached spectroscope of considerable dispersive power is given a uniform motion across the axis of the collimator. Before the stationary photographic plate at the focus of the observing telescope a second slit moves at such a velocity that a given prominence line constantly falls upon the plate.§

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* *Comptes rendus*, t. 88, p. 374.

† *Comptes rendus*, t. 91, p. 12.

‡ See note by Abney, Schellen's *Spectrum Analysis*, 2d English Edition, p. 372.

§ *Technology Quarterly*, November, 1890; *Astronomische Nachrichten*, No. 3006.

My experiments in solar prominence photography made at the Harvard Observatory during the winter of 1889-90 were restricted to the first of the above methods. The mirror of the horizontal telescope employed was so greatly distorted by the Sun's heat that it was never even possible to see the prominences well, and photography under such conditions was quite out of the question. The means used to move the photographic plate at the focus of the large diffraction spectroscope were moreover inadequate, and no valuable results were obtained. Knowing nothing at that time of the exceptional advantages offered by the K line, and convinced that $H\gamma$ and *h* were by no means suited for the work, I lost much time in a search for a photographic plate sufficiently sensitive to the less-refrangible rays, in the hope that the C line, which serves so well in visual work, might also be employed for photography. But although many experiments were made with cyanin, alizarin blue and other dyes, the high degree of sensitiveness desired was never attained. In the spring of 1890 it became clear that further attempts with the horizontal telescope would be useless, and the work at Cambridge was discontinued.

In the autumn of 1890 a 12-inch equatorial refractor was ordered for the Kenwood Observatory, and in March, 1891, it was ready for use. This telescope, together with the large spectroscope permanently attached to it, has been already described.[*] Attention was first directed to the ultra-violet spectrum of the prominences, and the great brilliancy of the H and K lines in the photographs at once removed all difficulty in the choice of a suitable line for further attempts at photographing prominence forms. The constant presence of these lines, their sharpness and brilliancy, their suitability for photographic study with ordinary plates, and the peculiar advantages afforded by the dark bands in which they lie, left no room for doubt, and K was selected as the line to be used in future work. Incidentally the ultra-violet spectrum of the prominences was investigated, and the small number of lines at first found has now been increased to seventy-four.[†]

In the early experiments at the Harvard Observatory the photographic plate was carried at the focus of the observing telescope in a plate-holder sliding on *V*-shaped guides. This arrange-

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[*] *Sidereal Messenger*, 1891, p. 321. This spectroscope has been used in all of my photographic work on the prominences and faculæ. The observing telescope and collimator are each of 3¼ in. aperture and 42½ in. focus, and the 4 in. Rowland grating has 14438 lines to the inch.

[*] The Ultra-Violet Spectrum of the Solar Prominences, *Sidereal Messenger*, *June*, 1891 ; *Am. Jour. Sci.*, Aug. 1891 ; ASTRONOMY AND ASTRO-PHYSICS, vol. 11 (1892), pp. 50, 602, 618, 821.

ment was afterwards replaced by a small cylinder, mounted in a brass box with its axis parallel to the lines in the spectrum. A sheet of photographic celluloid film was wrapped around the cylinder, which was rotated with the film almost touching the second slit. By setting the grating at the proper angle the K line was made to pass through the second slit on to the sensitive surface at the focus. The K line (fourth order) being invisible, settings were made by calculating the wave-length it would have in the overlapping spectrum of the third order, and bringing this place into position by observing the spectrum through the second slit with a positive eye-piece.

Photographs showing the rough outlines of prominences were soon obtained, but they were much inferior to those taken through K with a simple wide slit. This was due to several causes, of which two were prominent: (1) The clepsydra used to rotate the cylinder was much too small (1 in. bore, 3 in. stroke), and the resulting motion of the film was not sufficiently regular; (2) It is practically impossible to adjust the motion of the film so nicely that it exactly equals that of the solar image.

This latter is a serious defect of my first method of prominence photography, and cannot be entirely removed in even a much more perfect form of the apparatus than that described above, on account of the variations in the apparent motion of the Sun. It is thus almost impossible to prevent distortion of the image, and this distortion is more likely to be a variable than a constant quantity. Another difficulty lies in the fact that the motion of the solar image must be exactly at right angles to the slit. When experience had emphasized these defects I decided to direct my attention to the development of the second method. Accordingly I devised a new form of clepsydra and a system of moving slits in June, 1891, to be adapted to the spectroscope used in all the previous work. The instrument was completed by Mr. Brashear in January, 1892.

Meanwhile I devoted considerable time to a study of the possibilities of the wide slit method, and obtained a large number of fairly good photographs of prominence forms in this way. The H and K lines in the fourth order spectrum were brought into the field, and the slit made tangent to the Sun's image at a point where observations through the C line had shown a prominence to be. With the most sensitive plates employed (Seed 26 x) the exposure was less than a second. As was to be expected, the sharpest photographs were obtained with the shortest possible exposure. The prominences were shown on the same plate in both the H and K lines. The images in the latter line were stronger and sharper than those in H, on account of the greater brightness of K, and the superposition on H of the image due to the adjacent hydrogen ϵ line. In rare cases the line hydrogen α_1 was bright enough to give a faint image of the prominence. But although they are by far the brightest lines in the prominence spectrum the images in H and K with a wide slit would be comparatively faint were it not for the protection afforded by the broad absorption bands. These allow the slit to be widely opened without much increase in the brilliancy of the background.

It has been already mentioned that photographs of prominence forms taken with a wide slit are of no great practical value. It is true that under good conditions reasonably good pictures can be obtained of single prominences,* but the least whiteness of the sky greatly impairs the result. It is evidently important in this class of work to use a spectroscope with very long collimator (of course retaining the proper ratio of aperture to focus), in order that a wide slit may be used. The method is restricted by the fact that prominences of exceptional height cannot be photographed on account of the necessity of limiting the width of the slit.

In a paper presented to the Académie des Sciences in August, 1891, M. H. Deslandres describes some experiments made at the Paris Observatory in photographing the ultra-violet spectrum of the prominences, which confirm my earlier work. M. Deslandres had made no photographs of the *forms* of prominences, but suggested a method of doing so in the following words:

> "M. Hale, qui, depuis longtemps, s'occupe de cette dernière question, a proposé plusieurs systèmes fort ingénieux, avec une fente étroite; mais ces systèmes ne s'appliquent qu' à une protubérance isolée, et non au pourtour entier du Soleil; de plus, ils ne donnent pas les vitesses. Je me suis arrêté à un dispositif tout différent, qui est le suivant:
>
> "Le spectroscope, qui peut être quelconque, tourne tout d'une pièce autour d'un axe passant par le centre de l'image solaire et prolongeant l'axe optique de l'objectif. Le milieu de la fente est sur le bord solaire dont il rencontre successivement tous les points par la rotation de l'appareil. Devant la plaque photographique, on place une fente fixe qui correspond à la raie K du calcium. De plus, la plaque est mobile, de manière que, à un deplacement du milieu de la fente, corresponde un déplacement égal de la plaque. Ce résultat est assuré par de simples engrenages. Si donc le spectroscope tourne d'une manière continue avec une vitesse convenable, on obtient. sur la plaque, une bande de longueur égale à la circonférence du Soleil, qui donne toutes les protubérances avec leur forme exacte.

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* One of these has been reproduced in my paper "Recent Results in Solar Prominence Photography," ASTRONOMY AND ASTRO-PHYSICS, January, 1891.

Mais la vitesse des protubérances n'est pas donné par ce procédé. Aussi convient-il de donner à l'appareil une serie de rotations rapides, separées par des poses de deux secondes, de manière à avoir sur la plaque, par example, 200 sections équidistantes de la chromosphère sur tout le pourtour solaire. Chaque section demandant environ trois secondes, on peut avoir l'ensemble en dix minutes. Si, d'ailleurs, on replace la plaque par un papier sensible enroulé sur des cylindres, et si le mouvement du spectroscope est rendu automatique, on obtient un appareil simple qui enregistre d'une manière continue la forme et la vitesse des masses incandescentes à la surface du Soleil."*

M. Deslandres' criticisms of my method are evidently inexact, for the prominences around the entire circumference of the Sun are well shown in a single photograph, and the velocities both in the line of sight and normal to it are respectively obtained by photographs of the distorted H and K lines and by a series of photographs of prominence forms taken at known intervals of time.

M. Deslandres' proposed apparatus has never been constructed, and he has hitherto obtained no photographs of the forms of prominences or faculæ. The proposed instrument is like that already described as having been devised by Dr. Lohse, and employed unsuccessfully in his experiments at Potsdam. The only change suggested is the motion of the plate across the second slit, giving the chromosphere in a straight line instead of in a circle. To anyone familiarized by experience with the necessity of avoiding complication in the apparatus, this proposed addition would be regarded rather as a defect than an improvement. Any slight variation in the motion of the plate would cause a distortion of the image, as already referred to in an enumeration of the disadvantages of my first method. M. Deslandres' apparatus has the same good and bad points as Dr. Lohse's rotating spectroscope, except in the important advantage arising from the use of the K line.

The first experiments with my improved apparatus in January, 1892, completely justified my anticipations of success. Not only was the entire chromosphere obtained in a single operation, but, with a shorter exposure, and the diaphragm between the slit and solar image removed, the faculæ in even the brightest parts of the disc were readily photographed. Plates taken with a double exposure showed the disc of the Sun with the faculæ and spots, and the encircling ring of chromosphere and prominences. Once adjusted the spectroheliograph proved to be simple and convenient in operation, and it has ever since been in constant use.

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* *Comptes rendus*, 17 Août 1891.

In order to discuss intelligibly the advantages and disadvantages of this form of spectroheliograph it will be necessary to briefly describe its mode of construction. The essential parts are two movable slits, one at the focus of the collimator of a large grating spectroscope, and the other just within the focus of the observing telescope. The slits are about 3¼ inches in length, and adjustable in width. They are attached to carriages mounted on steel balls, so that they may be moved with perfect freedom across the axes of the tubes, in the direction of the length of the spectrum. A photographic plate-holder is supported just beyond the second-slit, and, after drawing the slide, the plate-holder can be pushed forward by means of a cam until the surface of the plate almost touches the jaws of the slit. A small 90° reflection prism is attached to the slit carriage on the side toward the grating, and by a suitable combination of lenses a small portion of the spectrum can be viewed without disturbing the plate holder. This has not been used in practice, the K line being brought on to the slit by observing it directly with a low-power positive eye-piece. The motive power is supplied by a specially designed cepsydra, which is mounted within the braced frame of the spectroscope. It consists of a brass cylinder of 3 inches bore and 6 inches stroke, supplied with two inlet and two outlet valves, and a very accurately made micrometer gate-valve. The piston has a cup-shaped leather packing, and the phosphor-bronze piston-rod passes through a stuffing-box in the upper head. At the end of the rod a system of bell-crank levers is attached, and these convey the motion to the slit at the focus of the observing telescope. An extension of the piston-rod passes through a guide in the upper frame of the spectroscope, and connects with the first slit by another lever system. It will be seen that when the piston is set in motion, the two slits will move simultaneously, and in opposite directions. The collimator and observing telescope are inclined to each other at an angle of 25° ; they are exactly alike in aperture (3¼ inches) and focal length (42½ inches). A 4-inch Rowland grating with 14438 lines to the inch stands at the point of intersection of their axes.*

The obvious advantage of this form of spectroheliograph over others previously described is in the small weight of the moving parts, and the ease with which it can be constructed from an ordinary solar spectroscope. But while successfully accomplishing the work for which it is intended, the instrument has one impor-

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* A fuller description of this instrument is given in ASTRONOMY AND ASTRO-PHYSICS, May, 1892, p. 407.

tant disadvantage. I refer to the distortion of the image resulting from the motion of the slits.

In the equation for the plane reflection grating

$$\lambda = \frac{d}{n}(\sin \theta \pm \sin \omega)$$

θ = angle of diffraction,
ω = angle of incidence,
λ = wave-length of line observed,
n = order of spectrum employed;
d = distance between adjacent lines of grating.

Then

$$\sin \theta = \frac{n\lambda}{d} \pm \text{F} \sin \omega.$$

Differentiating, we have

$$d\theta = \frac{\cos \omega \, d\omega}{\cos \theta}, \qquad (1)$$

$\frac{n\lambda}{d}$ being a constant for a given line.[*]

In the case of the Kenwood Observatory spectroheliograph, when used in photographing an image of the Sun 51 mm. in diameter, we have

θ (maximum) = 14° 36′
θ (minimum) = 13° 42′
ω (maximum) = 40° 54′
ω (minimum) = 38° 42′
$d\omega$ = 51 mm.

Substituting in (1), we find

$$d\theta = 39.8 \text{ mm.}$$

That is, the diameter of the photographed solar image which is parallel to the length of the spectrum will be reduced by the distortion from 51 mm to 39.8 mm. The diameter parallel to the lines of the spectrum will of course remain undistorted.

This result, however, is only an approximate one, for the distortion for equal values of $d\omega$ increases from one side of the image to the other.

Thus if we make $d\omega$ = 1 mm, and calculate the values of $d\theta$ for one side, the center and the other side of the solar image, we obtain the respective values

$d\theta$ = 0.78 mm (for maximum value of θ)
= 0.79 mm (for mean value of θ)
= 0.80 mm (for minimum value of θ).

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[*] See Young, *Amer. Jour. Sci.*, November, 1880.

In measuring photographs distorted in this way the necessary correction for a point at a given distance from the Sun's limb may be taken from a table of corrections, which is readily constructed for a given position of the Sun's image with respect to the axis of the collimator. In work with this form of spectroheliograph it is therefore desirable to provide means for placing the solar image exactly in the center of the collimator. It is also convenient to orient the image so that the distorted axis shall be parallel to the solar equator in the photograph. For this purpose the whole instrument can be rotated about the axis of the collimator, the direction of the slit being read off on a position circle. The parallel lines on the photographs, which are due to dust on the slit, and cannot be altogether avoided in any form of spectroheliograph when the slit is narrow, are made to serve a useful purpose in the orientation of the image.

The distortion just mentioned might be compensated by introducing a cam to move the photographic plate, the form of the cam being calculated from the equation given. Undistorted copies can be made from distorted photographs by means of a simple device of the writer's. The distorted photograph is projected by a suitable lens on to a screen, in which there is a slit parallel to the long axis of the image, and exceeding it in length. Just beyond the screen, and supported in a light frame of brass tubing in the focal plane of the lens, is the photographic plate. The screen and frame are so connected that while the slit moves across the short diameter of the image, thus giving the exposure, the plate moves in the opposite direction a distance equal to the difference between the long and short diameters of the image. A cam calculated from equation (1) secures the proper ratio of the two motions. Thus circular images of any desired size are obtained.

There remains to be mentioned another source of distortion, which has a slight but still appreciable effect on the photographed image—the curvature of the lines of the spectrum. Were prisms employed the curvature would be pronounced, and the distortion serious. With gratings the curvature is very slight. With the solar image central, and the slit parallel to the Sun's axis, the distortion at any point due to curvature of the lines is evidently a function of the heliocentric latitude, and may be so tabulated. The second slit of a spectroheliograph should have the same curvature as the K line.

The ratio of aperture to focal length in the collimator of a spectroheliograph, is not, as in a spectroscope, equal to the ratio of aperture to focal length in the equatorial to which it is attached. The collimator objective must have a larger angular aperture, in order that light from the edge of the Sun's disc may not be lost when the slit is in its extreme positions. The same holds true even if the slit is fixed in the axis of the collimator, for without large angular aperture light from the upper and lower portions of the image would be lost.

Let

F = focal length of equatorial (inches),
A = aperture of equatorial,
f = focal length of collimator,
d = diameter of solar image at focus of equatorial,
a = required aperture of collimator.

Then,

$$a = \frac{5d}{4} + \frac{Af}{F}$$

With this aperture no light will be lost up to a distance of about 4′ from the Sun's limb. Prominences of greater height are exceptional, and can be photographed singly in the center of the field. It will be seen that these conditions are not met in the Kenwood Observatory spectroheliograph, as this instrument was primarily intended for a solar spectroscope. The chromosphere and prominences are therefore photographed at a disadvantage, and the contrast in brilliancy between the limb and center of the solar disc is abnormally great in the negatives.

The effect of motion in the line of sight must now be considered The slight displacement of the K line due to the axial rotation of the Sun is altogether inappreciable, and may be neglected. Eruptive prominences, on the other hand, offer difficulties both to the spectroscope and the spectroheliograph. When the motion in the line of sight is large, and unequal in different parts of the same prominence, neither instrument will allow the true form to be distinguished. In the case of a wide-slit observation with the spectroscope rapid motion in the line of sight will cause the portions involved to be displaced from their normal positions in the image. As a result the form of the prominence will be distorted, unless every part of the prominence has the same radial velocity at the same time. In this exceptional case the entire prominence form would be displaced in the spectrum, but not distorted. In the spectroheliograph, or in any instrument for photographing prominences through a narrow slit, the effect of motion in the line of sight would be the same as in the case of the spectroscope, until the displacement became so great as to throw the K line entirely outside of the second slit. The portion of the prominence moving with sufficient radial velocity to produce so large a displacement would not appear in the photograph. As the second slit is rather wide in practice difficulties of this sort are rare.

The images of Sun-spots in photographs of the solar disc taken with the spectroheliograph depend as to their sharpness on several conditions. Most important of these is the width of the slits. With the width necessary for faculæ and prominences it is clear that the spots must be very poorly defined. Other conditions which conspire to bring about the same result are the superposition of faculæ on the spot-penumbra, and the comparatively long exposure required.

In a modified form of the Kenwood Observatory spectroheliograph which I have designed for the 40-inch equatorial of the Yerkes Observatory a single objective or a concave mirror will serve for both collimator and observing telescope, the second slit being placed immediately below the first slit. The slit-carriages will be connected with each other and with the clepsydra by an adjustable fork, thus allowing the proper relative motion to be obtained. It will be seen from equation (1) that the distortion of the image will be very small in this special case. Precautions will be taken to obviate difficulties arising from the diffuse light and the rather imited field peculiar to this form of the instrument.

I have also devised an automatic spectroheliograph to be used with a large heliostat and an objective giving a three-inch image of the Sun. Photographs taken with this instrument will be free from all distortion, except the very slight amount due to the curvature of the lines in the grating spectrum, and this may readily be allowed for. A rigid frame is carried on wheels of large diameter, running on ball bearings. The tracks on which the wheels rest are parts of a single casting, and are placed truly parallel; the heavy casting is bolted to a stone pier, the tracks having first been placed horizontal and at right angles to the meridian. The carriage can thus be moved several inches on the tracks in an east or west direction, a clepsydra furnishing the motive power. Attached to the carriages are two telescopes with their axes parallel. They are exactly alike in focal length (about three feet) and aperture, the latter being calculated by the expression given above. Each telescope has a vertical fixed slit in its axis at the focus of the objective. One of the telescopes serves as a collimator, and a plane Rowland grating standing on the carriage receives parallel rays from it. The length of the lines on this grating is equal to the aperture of the collimator. The width of the ruled surface is equal to the projection on the grating of the horizontal width of the illuminated portion of the collimating objective, the grating being set at the proper angle for use. The spectrum is thrown upon a plane silvered-glass mirror, fixed at an angle of 45° with the axis of the second telescope, and is thence reflected to the second slit. The K line passes through the slit and falls upon a sensitive plate.

The operation of the instrument is simple. The Sun's image having been formed by the large objective, and the K line set on the second slit, it is only necessary to place the photographic plate in position, and open the valve of the clepsydra. The first slit then passes over the solar disc, and the photograph is secured. The adjustments remaining the same, the second photograph is obtained on the back stroke, and so on indefinitely. The valve of the clepsydra, and the apparatus serving to change the plates are controlled by electricity. The former is a four-way valve, and takes the place of the five valves used on the clepsydra of the present Kenwood Observatory spectroheliograph. The plate-changing apparatus consists simply of a wheel about four feet in diameter, with its plane in the focal plane of the spectroheliograph. Three dozen sensitive plates (4 × 5 inches) are carried in clamps on the circumference of the wheel. A simple device controlled by an astronomical clock operates the clepsydra valve and moves the wheel through $\frac{1}{36}$ of its circumference at the proper time intervals. Thus photographs of the Sun can be taken automatically with any desired frequency.

This automatic spectroheliograph has not yet been constructed. It is possible that it may be found desirable to substitute a single objective for the two objectives and plane mirror of the original design. The freedom of the image from distortion and the comparatively small number of lines required on the grating are important advantages of this type of spectroheliograph; it is evidently unsuitable for use on an equatorial, but mounted on a solid pier in a dark room, it will evidently prove serviceable when employed with a good heliostat.*

KENWOOD OBSERVATORY, University of Chicago.

Feb. 14, 1893.

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* There remains to be described a form of spectroheliograph in which a single concave mirror replaces the two objectives ordinarily used. This arrangement has been adopted in my apparatus for photographing the corona without an eclipse. Should the experiments shortly to be undertaken with it prove successful, the instrument will be discussed in a future paper in connection with certain considerations involved in thus photographing an object giving a continuous spectrum.

RESEARCHES ON THE SPECTRUM OF β LYRÆ.[*]

A. BELOPOLSKY.

The researches on the spectrum of β Lyræ which I have made with the new spectrograph and the 30-inch refractor of the Pulkowa Observatory by means of orthochromatic plates, relate chiefly to the region between H_β and D_3.

The seventeen photographs show the following:

The dark and bright lines are present. The dark lines are especially numerous, delicate and distinct in the region between H_γ and H_β. Another kind of dark lines which particularly characterizes the spectrum, is broader than the first and very distinct, with bright edges which can sometimes be regarded as independent bright lines. The D_3 line is bright. The continuous spectrum becomes at times very weak.

Especially to be mentioned is the line at λ 5014. While the others disappear at times this line is always present, but its bright edges become weak and even entirely vanish (Sept. 24).

The F and D_3 lines must be specially investigated.

The former is generally seen double (Aug. 30 to Oct. 3 inclusive). The brightness and breadth of the components vary. Sometimes both are equal and between them is a narrow dark line; now the one is broader than the other, or the reverse; now one of them disappears, and in its place appears a rather broad dark line; now both are seen as bright lines, and on one side is a broad dark line. If we represent by *R* that one of these lines which is displaced toward the red, as compared with the hydrogen spectrum, and by *V* the other line, we find the following differences of wave-length between them and the F line of the comparison spectrum; *DR* and *DV* represent the dark lines.

1892	*R* Tenth-metres	*V* Tenth-metres	*DV* Tenth-metr's	*DR*
Sept. 7	—	2.94 diffuse	—	1.00 weak
8	3.25 distinct	3.63 distinct	—	7.53 broad, distinct
18	2.54 distinct	3.72 weak	0.03	—
19	3.39 distinct	—	—	—
20	2.21 weak	3.43 distinct	0.16	—
23	1.96 bright	2.99 diffuse	0.35	—
24	1.73 bright, narrow	3.41 diffuse	0.94	—
25	2.44 distinct, sharp	—	—	—
27	2.37 distinct, broad	—	2.51 broad	—
30	3.01 broad	2.29 narrow	0.38	—
Oct. 2	2.65 broad	3.23 broad	0.24	—
3	3.79 broad	3.06 broad	0.08	—

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[*] Translated from *A. N.*, 3129.

The probable error of each of these numbers is ± 0.20 tenth-meters.

The D_3 line, as has long been known, disappears from time to time and this is also shown by my photographs; but beside this it is double. I cannot decide whether a dark line appears between the components, as the continuous spectrum is quite weak even at λ 5750, and the D_3 line stands quite isolated.

It is double on the 4th and 30th September, and particularly sharp on the very good plate of Sept. 30. The difference of wave-length on this day is 8.2 tenth-meters.

Other aspects of the line are as follows:

Aug.	24	very bright, single.
	25	very bright, single.
	30	missing; plate fogged.
Sept.	4	distinct, double.
	7	distinct, single.
	8	very narrow, single.
	18	perhaps traces.
	19	very weak.
	22	invisible; plate weak.
Sept.	23	missing; plate good.
	24	very weak; plate good.
	25	only traces; plate weak.
	27	very weak.
	30	very bright, double.
Oct.	1	very weak; plate weak.
	2	distinct, single.
	3	weak; plate good.

As for the other lines, I shall reserve a detailed description until I possess more abundant photographic data; I shall here give only provisional wave-lengths obtained from the measurement of a single plate. They are as follows:

5876.2	bright
5864.2	dark
5703.3	bright edges
5600.0	dark
5464.0	bright
5433.1	dark
5429.7	"
5386.3	"
5380.2	"
5316.2	"
5272.1	"
5234.8	"
5230.5	bright
5223.4	"
5207.6	dark
5190.9	"
5170.3	dark
5162.9	"
5150.1	"
5056.1	"
5017.7	bright edge
5014.3	dark, bright edges
5005.4	
4964.2	dark, bright edges
4922.7	" " "
F	
4821.8	dark
4736.2	"
4714.3	"
4706.9	"
4701.6	"
4651.8	dark
4633.4	"
4622.2	"
4583.0	"
4575.3	"
4564.6	"
4557.1	"
4553.3	"
4547.5	"
4531.7	"
4529.0	"
4512.9	"
4509.9	"
4506.6	"
4481.3	bright edges

The wave-lengths printed in italics belong to the sharpest lines.

The explanation of the most interesting phenomenon must be deferred. It seems that a dark line in the region of F moves to and fro, and modifies the appearance of a bright one. The double D_3 line apparently indicates a close double star; period 26 days?

I must also mention that no traces of D_3 are to be seen on three photographs of the spectrum of γ Cassiopeiæ.

PHOTOGRAPHY OF THE SOLAR CORONA WITHOUT AN ECLIPSE.*

GEORGE E. HALE.

In a recent number of the *Comptes rendus*† M. Deslandres describes some attempts made at the Paris Observatory to photograph the solar corona without an eclipse. Two exactly similar prisms are placed with their faces parallel, and the base of one opposite the refracting edge of the other, as in Newton's classic experiment on the recomposition of light. Instead of being placed very close together, however, the prisms are separated by a considerable distance, so that the second prism receives only a portion of the spectrum formed by the first. Sunlight being employed, and the recomposed light on its emersion from the second prism falling on a lens or mirror, a colored image of the Sun is obtained. If one of the prisms is displaced perpendicularly to the line joining the two, all the colors of the spectrum enter successively into the formation of the image. The idea is to photograph the surroundings of the image with light of various colors, in the hope of finding that at some region of the spectrum the light of the corona is so much brighter than the diffuse light of the sky that photographs of the form of the corona can be obtained without an eclipse. On certain of M. Deslandres' plates, especially those for which ultra-violet light was used, corona-like forms appear around the solar image; but that they truly represent the corona, and do not result from instrumental or photographic defects, has yet to be established, as M. Deslandres himself points out.

At a meeting of the Section of Mathematics and Astronomy of the Chicago Academy of Sciences on Dec. 6, 1892, I described in detail a method of photographing the corona without an eclipse, devised by myself in April, 1892, which is based on exactly the same principle. I proposed to isolate light of any desired wavelength by means of a spectroheliograph, and thus to photograph the sky surrounding the Sun, employing such a region of the spectrum as experiment proved to be best adapted to show the corona on the background of the sky. Professor Vogel's measures of the absorption of the solar atmosphere at the center and edge of the disc show that the absorption increases more rapidly for short than for long waves. In his experiments on photographing the corona without an eclipse Dr. Huggins recognized

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* Communicated by the author.

† *Comptes rendus*, Jan. 23, 1893.

this fact, and endeavored to restrict photographic action to the blue rays of the spectrum by the use of colored glass screens, and specially prepared plates. Results obtained in this way, while not demonstrating with certainty that the photographs truly represent the corona, were more encouraging than those secured with absorbing media of other colors.* In my own consideration of the subject I was led by Professor Vogel's measures to believe that, within certain limits, the brightness of the corona with respect to the surrounding sky is inversely proportional to the wave-length of the light employed for the observation. It would thus seem desirable to employ ultra-violet light in future photographic experiments.

In May and June, 1892, I attempted to photograph the corona with the spectroheliograph of the Kenwood Observatory. The first slit was made rather wide and the grating set at such an angle as to bring a portion of the ultra-violet of the first order spectrum on to the second slit. The direct light of the Sun was prevented from entering the spectroheliograph by means of a diaphragm somewhat larger in diameter than the solar image. Photographs were obtained which resembled the corona, but I greatly doubted whether the images were not of instrumental origin, or due to haze or passing clouds. Appreciating the importance of the question, I decided to construct an instrument for the express purpose of photographing the corona. The work was undertaken in August, but on account of various delays it has not yet been completed. The apparatus will be carried on a small equatorial mounting. A silvered glass concave mirror of 6½-inches aperture and 50 inches focus, made for this purpose by Mr. Brashear in September, forms an image of the Sun on a diaphragm, which excludes all of the direct light of the disc from the spectroheliograph. The latter is similar to the spectroheliograph I now use for photographing the prominences, though a single concave mirror is employed instead of two objectives in the collimator and observing telescope. The apparatus will be tried in Colorado or Arizona during the coming spring or summer, as the low Sun and whiteness of the sky make experiments in Chicago useless, at least during the winter months.†

An apparatus in all respects like that of M. Deslandres was devised some years ago by Professor Wm. Harkness for the purpose

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* Dr. Huggins has kindly presented me with one of his photographs on which the image appears remarkably like the corona.

† For previous references to this method of photographing the corona without an eclipse see ASTRONOMY AND ASTRO-PHYSICS, November, 1892, p. 792; January, 1893, p. 95; *Photo-Beacon*, February 1893.

of observing the corona without an eclipse,[*] but it has ever been given a practical test.

KENWOOD OBSERVATORY, University of Chicago,
Feb. 15, 1892.

DISTRIBUTION IN LATITUDE OF SOLAR PHENOMENA OBSERVED DURING THE THIRD QUARTER OF 1892.[†]

P. TACCHINI.

The following results were determined for each zone of 10°, in both hemispheres of the Sun:

Latitude.	Prominences.		Faculæ.		Spots.		Eruptions.	
90° + 80°								
80 + 70	0.007	0.467						
70 + 60	0.114							
60 + 50	0.044							
50 + 40	0.048		0.004	0.502				
40 + 30	0.063		0.020					
30 + 20	0.083		0.097		0.078	0.455		
20 + 10	0.066		0.215		0.233		0.445	0.667
10 . 0	0.042		0.166		0.144		0.222	
0 − 10	0.067	0.533	0.081	0.498	0.045	0.545	0.000	0.333
10 − 20	0.055		0.146		0.256		0.000	
20 − 30	0.101		0.170		0.222		0.222	
30 − 40	0.109		0.089		0.022		0.111	
40 − 50	0.067		0.008					
50 − 60	0.117		0.004					
60 − 70	0.015							
70 − 80	0.001							
80 − 90	0.001							

The eruptions occur nearest the solar equator, while all the other phenomena are always found in higher latitudes. As in the preceding quarter the faculæ, spots and eruptions have their maximum frequency at the same distance north and south of the equator, while the prominences have their maximum at a greater distance, in zones where there are neither spots nor metallic eruptions. It should also be remarked that in the equatorial zone (+ 20° — 20°), where the maxima of faculæ, spots and eruptions occur, the prominences show a relatively small frequency; this would lead one to consider a great number of prominences as the product of conditions very different from those which give rise to spots in the photosphere, while prominences form in the atmosphere of the Sun, and at a very great distance from the limb. This was the case in the prominence which I observed on April 1,

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[*] *Bulletin Philosoph. Soc., Washington,* vol. 3, p. 116-119; *Beiblætter,* vol. 5, p. 128.

[†] Communicated by the author.

1892, at a distance of 264″.1 from the limb, which afterwards rose 100″ higher, thus attaining an elevation of more than 6 minutes, with no corresponding change at the surface of the Sun.

ROME, Italy, January 3, 1893.

SOLAR STATISTICS IN 1892.*

R. WOLF.

From the solar observations made at the federal Observatory at Zurich and the magnetic observations made at the Milan Observatory, I have deduced for last year, employing the method established by me some years ago, the following values for the monthly means of the relative numbers (r), the variations in declination (v), and the increments (Δr and Δv) which these quantities have received since the corresponding epochs of 1891:

	Zurich.		Milan.	
1892.	r	Δr	v ′	Δv ′
January	72.4	55.3	4.33	0.62
February	72.4	49.0	6.27	1.76
March	52.5	42.5	10.31	2.46
April	69.6	50.2	11.89	1.31
May	79.2	36.0	11.47	0.77
June	76.6	27.9	11.66	1.30
July	77.9	18.8	11.76	0.78
August	102.6	70.0	11.55	1.59
September	62.2	10.3	9.06	1.41
October	74.8	24.4	9.10	0.61
November	67.1	26.1	5.56	0.78
December	77.8	47.2	3.07	0.22
	73.8	38.2	8.91	1.13

It follows from this table that the relative numbers and the magnetic variations have both continued to increase considerably, and that the parallelism between these two series, so different in appearance, persists in a quite remarkable manner. This assertion will not be considered greatly exaggerated if it is considered, for example, that the formula,

$$v = 5'.62 + 0.045\, r,$$

which I formerly deduced for Milan, gives for last year

$$v = 5'.62 + 0.045 \times 73.8 = 8'.94,$$

i. e., a value which differs only $\frac{3}{100}$ from the result of observation.

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[*] *Comptes rendus* 30 Janvier, 1893.

SOLAR ELECTRO-MAGNETIC INDUCTION.*

M. A. VEEDER.

In order to determine what it is upon the Sun in any given case that produces an aurora, detailed study of magnetic phenomena is requisite. For the present purpose the pivotal facts respecting such phenomena are their periodicity corresponding to the synodic rotation period of the Sun, their brevity of duration, and abruptness and violence of beginning, and gradual subsequent decline. In conformity with these facts the centres of electro-magnetic activity in the Sun must occupy definite areas, and their inductive effects must be conveyed in accordance with a very sharply defined arrangement of the lines of force in a particular direction chiefly. It is evident also that the Earth must come into range with these lines suddenly, the beginnings of magnetic storms being abrupt and strong and, whenever they occur in the usual series, at the exact interval from each other of the rotation period of the Sun. The endings of such storms on the contrary are gradual and non-periodic, the Earth requiring three or four days commonly to pass out of range. It would seem that this manner of beginning and ending could not co-exist with the location of the originating solar disturbance elsewhere than at the eastern limb. If at the meridian especially the beginnings and endings ought to correspond with each other and to be equally ill-defined and non-periodic, which is not the case.

The period of auroral recurrence has been found to be twenty-seven days, six hours and forty minutes, corresponding accurately to the time of a synodic revolution of the Sun as determined from the average rate of rotation of spots. This period may be termed the solar magnetic month, and it will be of service to construct a calendar based upon it. For this purpose any date whatever may be selected as the starting point from which to begin the enumeration of these solar magnetic months. In order to provide for the fractional parts of a day, each fourth period requires to be lengthened one day so as to comprise the six hours, and likewise each thirty-sixth period so as to comprise the forty minutes. It is evident that on corresponding days of these periods the Sun will always return to the same position in longitude relative to the Earth. Thus this system of dating enables comparison to be made readily as to the facts attendant upon such returns of the Sun to particular positions. The more ex-

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* Communicated by the author.

tensively this method of recording the phenomena in question is employed the clearer does it become that there can be no error in the length of the period adopted of sufficient extent to obscure the leading facts and relations. The writer has a diary covering many years dated in accordance with this plan, and likewise extensive tables of auroras and magnetic storms based upon it. It has thus been found that it is most important to record under the appropriate dates the distribution of sunspots and faculæ, the prevalence of auroras, magnetic storms and thunderstorms, and any evidence of sudden and widespread intensification of storms, and likewise the movements in latitude and longitude of anti-cyclones, these being the features which give evidence of being related to solar magnetic induction.

By means of such a record the periodicity of the aurora at the interval named is most finely shown. At times also the substitution and intermingling of thunderstorms on auroral dates becomes a notable feature. Especially important also is the evidence thus obtained that portions of the Sun much frequented by spots are invariably at the eastern limb whenever auroras are in progress. On the other hand, however, the presence at the eastern limb of such a disturbed portion of the Sun does not always insure the appearance of the aurora. Proximity to the plane of the Earth's orbit as well as to the eastern limb appears to be requisite for the production of the aurora and when this is lacking increase of thunderstorms occur instead. Whenever the solar conditions are favorable for the exercise of inductive effects in the manner which has been indicated, intensification of storms follows, and there is a general eastward movement of anti-cyclones. These atmospheric effects are most pronounced near the equinoxes, at which seasons also auroras are brightest and most frequent. In years of great auroral frequency the spots on the Sun and likewise anti-cyclones on the Earth are more persistent than usual in high latitudes.

Thus far the enumeration has been confined as far as possible to the simple facts of observation most prominently displayed in the records. There are in addition certain obvious inferences in regard to the constitution of the Sun and its modes of activity which demand consideration. The fact that the electro-magnetic centers upon the Sun, unlike the spots, remain stationary for extended periods is strong evidence of the existence of a solid nucleus in which they are located. Their mode of action is essentially volcanic, and consequently fitful and irregular. This is the chief element of uncertainty in the entire subject, and is the explanation of many features otherwise anomalous. If, for example, an eruption occurs at the proper instant in the rotation period so that its entire inductive effect is extended along lines of force which embrace the Earth, a tremendous impulse may be experienced from a relatively small outbreak. In like manner a greatly disturbed portion of the Sun may happen to be temporarily quiet at the critical hour and so produce small effect. The sources of these fitful variations are hidden from view in the depths of the Sun, and consequently must remain perplexing. The times and places of their activity may perhaps be determined but not the extent for even so long a period as a single hour in advance. It is plain from the various considerations that have been advanced that the sun does not produce magnetic storms in virtue of its being a magnet as a whole. On the contrary it is the turmoil of eruption at particular points which originates a state of electrification in the overlying cooler portions of the Sun's surroundings. The motion of rotation carrying forward these electrified areas developes currents in the vicinage dynamically. Under the physical conditions existing in interplanetary space, cosmical dust and *debris* there sufficiently abundant to shine by reflected sunlight as the zodiacal column, furnishes a conducting medium well fitted to convey by induction these solar electro-magnetic impulses to vast distances.

The purposes of the present very brief summary is to emphasize the fact that electro-magnetic periodicities afford a secure basis for extended research in the department of solar physics. The tables and diaries to which reference has been made and which contain detailed proofs of the points here outlined are very voluminous and are not in a fit condition for publication. They constitute the crude material which is in process of being worked up. Specimen extracts from some of them are in print, however, and copies of these will be furnished freely as long as the supply lasts to any who may be sufficiently interested to apply for them.

LYONS, N. Y., Feb. 7th, 1893.

ECLIPSE PHOTOGRAPHY.*

A. TAYLOR.

Photographing the corona during an eclipse of the Sun is not such a simple operation as one might at first imagine. We may recognize in the corona at least four main portions differing in intensity of light—the chromosphere and prominences; the brilliant inner corona with the polar rays; the middle corona, which we may take as extending from 10′ to 30′ from the limb; and the faint extensions which have been traced visually for several degrees from the limb, and which are only very slightly brighter than the surrounding sky.

It is obviously impossible to photograph all these in a satisfactory manner with one exposure. Different exposures must be given to get the different portions of the corona, and a uniform scale on the margins of the plates will enable the relative intensities of the photographic effect to be measured.

M. de la Baume Pluvinel, in a very interesting and valuable paper in Vol 6, No. 9, of the records of the Société Astronomique de France, gives a useful discussion of this question:—"The intensity of photographic action is equal to the product of three factors: the effectiveness of the object-glass, the duration of exposure, and the sensitiveness of the plate. If we indicate the useful diameter of the object-glass by a and the focus by f, the effectivenes defined by the International Congress of Photography is $100\frac{a^2}{f^2}$. On the other hand, if we take plates of gelatino-bromide of silver of normal sensitiveness as our unit, and let t be the length of exposure in seconds, we shall have the following formula to express the photographic action:

$$100\frac{a^2}{f^2}t.$$

"Working with plates of wet collodion, this expression must be multiplied by $\frac{1}{30}$, and with plates of dry collodion by $\frac{1}{300}$. The first photographs of the corona taken with wet collodion from 1868 to 1878 were obtained with a photographic action not greater than 2. Later, thanks to rapid processes, we could obtain plates much more impressed. Thus, in 1883, a photograph obtained by M. Janssen had received a photographic action equal to 918. On the negative thus obtained the corona extended to

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* From *The Observatory*, February, 1893.

between 30′ and 40′ from the limb of the Moon, but details of the parts near the Sun were completely wanting. We might ask whether by still further increasing the photographic action we should also extend the limits of the phenomena. Certainly not! for if the photographic action is too intense the faint contrast between the extreme parts of the corona and the sky, which is always more or less illuminated, is no longer appreciable on the negative. We know, indeed, that if we wish to produce a maximum contrast between two half-tones we must only use just enough light for the faintest of the half-tones to give a perceptible image. In America, Mr. Burnham has been engaged in determining the maximum length of exposure to give plates to obtain the best representation of the corona, and has made experiments on the subject by photographing the Moon and white clouds on a faintly illuminated sky."

We can scarcely accept this latter as a correct description of Mr. Burnham's experiments. He photographed the Moon in full daylight, and photographed brightly illuminated clouds round the Sun; the conditions in these cases being totally different from those of an eclipse. His experiments prove, what has never been disputed, that to get slight contrasts with great intensity of light, a long exposure is useless; but the problem with the faint extensions of the corona is to get slight contrast with faint light. My own experiments with the 20-inch mirrors of 45-inch focus at Ealing, when I photographed the Moon surrounded by clouds in faint twilight, were more comparable with the eclipse conditions; and I found that increase of exposure up to a minute gave greater extension, a result which the Eclipse Committee of the Royal Astronomical Society believed would be obtained by the long exposures with mirrors in eclipse work. One second exposure with the 20-inch mirrors will give a photographic action of 19.75 according to the formula, and 60 seconds exposure gives an action of 1185, but these results must be reduced, probably by 10 per cent, owing to loss of light by reflection.

M. de la Baume Pluvinel continues:—"At Salut Isles in 1889 I used five arrangements giving photographic actions varying from 185 to 13. However, doubtless on account of the peculiarly intense illumination of the atmosphere due to the short duration of totality and a great abundance of water-vapor, the negative corresponding to a photographic action of 30 was most satisfactory. But it is very probable that an equally good result might have been obtained with much less photographic action. Thus, Mr. Barnard, to whom we owe the best photograph of the eclipse of January 1, 1889, worked with a photographic action equal to 0.58."

It would be interesting to know why, if this is the case, the photographic action 30 was better than 13 with M. de la Baume Pluvinel, and why instantaneous pictures of the corona do not show greater extension than any others. At Salut Isles, Mr. Rooney exposed plates to photographic actions of 1.11, 2.22, 4.44, 44.44, 88.88, and 177.77, and his negatives show an increase of extension of the corona with every increase of photographic action. Father Perry, with the 20-inch mirror, obtained plates with photographic actions of 19.75, 98.75, 197.5, 395.0 and 790.0, always obtaining greater extension with greater photographic action. His photograph of 197.5 is not quite equal to Mr. Rooney's 177.76 plate, but the other two plates of Father Perry's series with greater photographic action show still greater extension. Comparisons of Mr. Rooney's photographs and those obtained by Father Perry, by the use of the formula given by M. Pluvinel, strengthen the opinion that the mirror was very probably dewed, but they clearly indicate that so far all the evidence is decidedly in favor of the idea that the greater photographic action gives the greater extension of the external parts of the corona.

Captain Abney finds that we may look upon a photograph as a drawing in which 200 different shades are used, or in other words, that on a correctly exposed negative differences of ½ per cent. in the intensity of light can be detected. It should therefore be possible by correct exposure to detect the corona on the sky when the skylight forms 99½ per cent. of the light and the corona ½ per cent. The correct exposure to detect this slight shade with faint light is totally different from that necessary to detect it with intense light. A certain absolute amount of light is necessary to begin *any* chemical change in a sensitive film, and in photographing extensions of the corona this limit must be reached and can only be reached by long exposure. In Mr. Burnham's experiments on photographing clouds round the Sun, the difficulty was not to get enough light *to start* photographic action, but to *cut down* the light so as to detect ½ per cent. of the total amount. Hence his experiments do not in any way bear upon the question of photographing the extensions of the corona.

The whole process of photographing the faint extensions of the corona is more fairly comparable with that of photographing nebulæ on a moonlight night, and it can scarcely be questioned that a long exposure and great photographic action in this latter case give the best results.

The most enthusiastic advocate of short exposure and small photographic action in the case of the corona would scarcely prefer 3 minutes to 60 minutes when photographing nebulæ on a moonlight night; and as the conditions are fairly comparable, it is difficult to understand why 3 seconds and small photographic action should be suggested for the corona extensions instead of 60 seconds and great photographic action. Of course short exposures are necessary to obtain the internal portions of the corona, but for the faint outlying portions only long exposures can reasonably be expected to give satisfactory results.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

Nova Aurigæ.—A photograph of the region of Nova Aurigæ was taken on the 3d of October, 1892, with the 20-inch reflector, and exposure of 110 minutes, upon which the Nova appears as a star, as well defined as any of the other stars, which are very numerous, on the plate.

There is no trace of nebulosity surrounding the Nova, or in its vicinity, and there is no feature about it suggestive that it is different from other stars.

The diameter of its photo-image measures 21 seconds of arc, and about 85 seconds distant from it, on the n. f. side, is a star, the photo-image of which measures 23 seconds of arc; the Nova is therefore 2 seconds in diameter less than the star.

On the 25th of December 1892 another photograph was taken of the same region, with an exposure of 20 minutes, upon which the Nova has a photo-image of 13 seconds of arc in diameter, and the star referred to has a diameter of 16 seconds. If we proportion the measured diameters, obtained on the days stated, we shall have the following:

$$23'' : 16'' :: 21'' : 14.63$$ — the diameter of the Nova.

But the diameter of the Nova measures only 13 seconds, which shows a decrease of 1″.63 in diameter, between 3d of October and 25th of December.

There is no indication of nebulosity round the Nova, or in its vicinity, on the December plate, and it appears as sharply defined as the other stars.

So far, therefore, as the evidence obtained by the twelve photographs which I have taken between the date of the appearance of the Nova and the 25th of December, there is nothing upon them indicative of a disturbance, such as we might expect to see recorded, if a body of the magnitude and velocity of the Nova had rushed into a nebula, or into a swarm of meteors. On the other side, it might be argued that the great velocity of the star would carry it through, without causing such great disturbance at right angles to the line of flight, according to dynamic law, that a projectile at a high velocity will penetrate through a plate of ron, or of glass, without fracturing them in the manner that a projectile would at a low velocity. On this hypothesis the inrush of the nebulous or meteoric matter, to fill the vacuum created by the star, might account for the spectra which were observed. ISAAC ROBERTS.

In a letter accompanying the above note Dr. Roberts adds:

"On my photographs I can distinguish between true nebulosity and atmospheric glare around a bright star, say, such as the stars in the Pleiades, which cannot be done by eye observation even by aid of the largest telescopes yet made, and 3″ arc is a measurable quantity on my negatives."

English Eclipse Parties.—In a letter dated Jan. 23, Mr. A. Taylor writes as follows:

"Two expeditions will be sent to observe. The African one will go to Fundium up the Salum River in Senegal. Four observers will go from Liverpool about March 18, and will be met at Bathurst by a British gunboat which will assist during the eclipse work. They will probably arrive at Fundium on April 2.

"The program for the African station will include photometric measures of the visual intensity of the corona similar to those made in Granada in 1886. Professor T. E. Thorpe and Mr. Gray will have charge of this portion of the work. Mr. A. Fowler will photograph the spectrum of the corona with a six-inch objective-prism spectroscope. Mr. J. Kearney will photograph the corona with one of the 4-inch lenses used in previous eclipses and a new Dallmeyer combination which, with a focal length of 5 feet 6 inches, will give a diameter to the moon of 1½ inches. Probably a 20-inch mirror will also go to Africa."

"At Para Curu near Ceara in Brazil, I hope to photograph the corona with a 4-inch lens and a Dallmeyer lens, and to photograph its spectrum with radial and tangential slits. I will let you have details of arrangements later. Mr. Shackleton will photograph the spectrum of the corona with a 3-inch objective prism spectroscope. The climatic conditions being unfavorable, we shall not take a 20-inch mirror to Para Curu."

Two American parties—one under Mr. Bailey of Harvard Observatory and the other under Professor Schaeberle of Lick Observatory—have already sailed for South America to observe the eclipse. A French party is now *en route* to Africa.

The Potsdam Measures of Motions of Stars in the Line of Sight.—An important feature of the volume in which Professor Vogel has published the result obtained with the Potsdam spectrograph has as yet, we think, scarcely received the attention which it merits. Next to the table of numerical results for the various stars observed, (to obtain which was, of course, the object of the whole investigation), the chief value of the book is in the vast amount of information which it contains, with regard to the details of the instruments and processes employed. The investigations recently completed at Potsdam involve no theoretical difficulties, so far, at least, as the main line of the research is concerned, as any uncertainty in the general application of Doppler's principle could not give rise to errors which need be considered in dealing with such moderate velocities as are met with in the stars. The difficulties are those of ways and means,—of instruments and methods of measurement. In many investigations well known methods are followed, and only sufficient reference to them is necessary to show that the customary precautions have not been neglected; but the application of photography to the measurement of the displacement of lines in stellar spectra was a new departure in spectroscopy, involving an immense amount of preliminary experiment, and a detailed description of all the processes is of the greatest value. Professor Vogel's book is a mine of information concerning dimensions of apparatus, instrumental errors, exposures, plates, etc., etc. The data which he has collected must be consulted by all who may seek to extend the work which he has begun, and the Potsdam spectrograph will serve as the standard by which the practical efficiency of future instruments will be measured.

Professor Vogel's results show that visual observations of stellar motions with small telescopes are now little better than a waste of time. A comprison of the Potsdam and the Greenwich measurements, made with telescopes of nearly the same aperture, shows very clearly the superiority of the photographic method, and all the more clearly because the skill of the Greenwich observer is unquestioned. To anyone who has ever tried to fix the exact center of a tremulous almost invisible line in a faint star spectrum,—an operation trying alike to eyes and nerves,—the cause of this superiority will be sufficiently evident. Prolonged exposure makes up for deficiency of light when photography is applied, and the length of the exposure may be increased until the effect of changes in the apparatus begins to show in the photographed spectra.

With very large apertures, visual observations will still be of value, particularly when the character of the spectra under examination is such that photographic processes cannot be advantageously applied. The results obtained by visual observations with the Lick telescope of thirty-six inches aperture are of the same order of accuracy as the Potsdam measures, as determined by comparing the results obtained for bright stars like Aldebaran and Arcturus; but for stars of the Sirian type, with broad diffuse lines, as well as for fainter stars, the advantage would lie with the Potsdam apparatus. Good results should evidently be obtained by applying photography to this class of work with large instruments, and although some difficulties are met with in doing this, the next important advance in the field opened by the Potsdam investigations will, no doubt, be the extension of the measures to stars below the third magnitude, by adapting the photographic method to telescopes of large aperture.

◆

Spectrum of Holmes' Comet.—A favorable opportunity for an examination of the spectrum of Holmes' comet, after the reported anomalous brightening on Jan. 16, did not occur at this Observatory until Jan. 29. The comet was then easily visible in the three-inch finder. With a low power on the 13-inch equatorial, it appeared as a round nebulous patch, brightening toward the center, where there was a small, ill-defined nucleus. With a single light flint prism on the large spectroscope (1.12 inches effective aperture), the spectrum was continuous, with a brighter streak running through it at the position of the nucleus. The bright moonlight caused the sky spectrum to be fairly bright, and the spectrum of the comet seemed to differ from the sky spectrum only in its greater intensity. On closing the slit to dim the sky spectrum, leaving it wide enough, however, to include the brightest central part of the comet, I thought at times that there was a brightening in the continuous spectrum at the position of the green carbon band, but could not be at all certain of its reality. It was, at any rate, perfectly evident that almost the whole light of the comet was represented in the continuous spectrum, which appeared to differ in no way from the spectrum which I observed on Nov. 16 and described in the December number of ASTRONOMY AND ASTRO-PHYSICS. Several attempts have been made to photograph the spectrum with low dispersion, but on no occasion has the sky remained clear for a sufficient length of time.

The hypothesis that this comet has been produced by a collision between two asteroids finds little support in the character of its spectrum. Instead of the bright line or banded spectrum which would result from the supposed collision, we have a continuous spectrum (possibly with traces of the usual carbon bands) which seems to be almost entirely due to reflected sunlight. The brightening observed on Jan. 16 was in all probability caused merely by an increase in the number of reflecting particles in the space surrounding the comet; that is, by an increase of density, which might result from a contraction following the previously observed expansion of the comet, or (which is more in accordance with the observations) from fresh emanations from the nucleus. In any case, the phenomenon is a remarkable one, and it is to be hoped that spectroscopic observations were somewhere obtained on or about Jan. 17, when the nucleus was brightest, and perhaps had a characteristic spectrum. J. E. KEELER.

Spectroscopic Method of Determining the Distances of Binary Stars.—Dr. Rambaut, in replying to a correspondent of *Nature* who suggests the above method points out that the idea is by no means new. Dr. Rambaut himself developed the method quite completely in the *Monthly Notices* for March, 1890. and gave a table of the velocities in the line of sight which might be expected in a number of well-known binaries. He is disappointed that astronomers engaged in spectroscopic determinations of stellar velocities have not paid more attention to this interesting subject. The difficulty is, of course, that the velocities to be expected in the case of a binary whose components can be optically separated are quite small and barely within reach of present methods.

Results of Stellar Spectrum Photography at South Kensington.—On December 8, Professor Lockyer communicated to the Royal Society the results obtained at South Kensington with a six-inch telescope, which has been used for the last two years in photographing the spectra of the brighter stars. Object-glass prisms with refracting angles of 7½° and 45° respectively were employed at different times to give the requisite dispersion.

The photographed spectra were tabulated with reference to the amount of continuous absorption in the violet, and all the 443 photographs are discussed from the standpoint of the meteoritic hypothesis. An abstract of the paper is given in *Nature*, Jan. 12, in which the spectra to be expected from a consideration of the meteoritic hypothesis, and the actual spectra as obtained by photography, are exhibited in parallel columns. The classification provides for both ascending and descending temperatures, the star α Andromedæ being selected as typical of the hottest stars.

Professor Lockyer considers that these photographs confirm the views which he has held until now as the result of visual observations. We must point out, however, that Professor Lockyer's identifications of stellar and terrestrial spectra are sometimes far from being well established; in some cases the identity can no longer be regarded as even probable.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR APRIL.

H. C. WILSON.

Mercury, having passed inferior conjunction on March 31, will be morning planet during April. He will reach greatest elongation, west from the Sun, 26° 56′, Apr. 28, but will probably not be visible to the naked eye.

Venus is approaching superior conjunction and will be too nearly in line with the Sun to be observed during April.

Mars will be visible in the west during the early evening. His course during April will be eastward through Taurus passing just north of the group of the Hyades.

Jupiter will be behind the Sun during April.

Saturn, having just passed opposition, is in its best position for observation for this year. The planet is just a little east of the star γ Virginis (see chart in Jan. No., p. 80) and moving westward. Saturn will be in conjunction with the Moon, 50′ north, April 27 at 11^h 30^m P. M. central time. The rings of Saturn will make an angle of about 7° with the line of sight during this month, so that they may be well seen.

Uranus also will be in good position for observation during April. He is about ⅓ of the way on a direct line from the bright star α Libræ to the faint naked-eye star λ Virginis (see chart p. 80). A telescope of moderate power will reveal the light green disc of the planet.

Neptune is past his best position for observation but may be seen in the early evening. He is moving slowly eastward about half way between the two third magnitude stars ε and τ Tauri (see chart in Dec. No. 1892 of this journal, p. 937). On the evening of April 12 Neptune will be 2° 35′ almost due south of Mars.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MERCURY.		
Apr. 5......	0 26.3	+ 4 44	5 07 A. M.	11 29.4 A. M.	5 50 P. M.
15......	0 18.0	+ 1 00	4 36 "	10 41.8 "	4 48 "
25......	0 34.6	+ 1 06	4 16 "	10 23.0 "	4 30 "
			VENUS.		
Apr. 5......	0 36.1	+ 2 22	5 27 A. M.	11 39.0 A. M.	5 51 P. M.
15......	1 21.7	+ 7 17	5 14 "	11 45.2 "	6 16 "
25......	2 08.3	+ 11 55	5 02 "	11 52.3 "	6 42 "
			MARS.		
Apr. 5......	4 12.7	+ 22 12	7 38 A. M.	3 15.0 P. M.	10 52 P. M.
15......	4 40.5	+ 23 16	7 21 "	3 03.5 "	10 46 "
25......	5 08.6	+ 24 02	7 04 "	2 52.2 "	10 39 "
			JUPITER.		
Apr. 5......	2 03.1	+ 11 28	6 18 A. M.	1 06.5 P. M.	7 55 P. M.
15......	2 12.1	+ 12 17	5 44 "	0 36.2 "	7 28 "
25......	2 21.4	+ 13 05	5 11 "	0 06.1 "	7 01 "
			SATURN.		
Apr. 5......	12 36.9	− 1 02	5 39 P. M.	11 37.9 A. M.	5 36 A. M.
15......	12 34.2	− 0 45	4 56 "	10 55.9 "	4 55 "
25......	12 31.7	− 0 30	4 14 "	10 14.1 "	4 15 "

URANUS.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Apr. 5	14 29.5	− 14 16	8 26 P. M.	1 30.2 A. M.	6 35 A. M.
15	14 28.0	− 14 08	7 44 "	12 49.3 "	5 54 "
25	14 26.3	− 14 00	7 03 "	12 08.4 "	5 14 "

NEPTUNE.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Apr. 5	4 30.7	+ 20 20	8 06 A. M.	3 34.1 P. M.	11 02 P. M.
15	4 31.8	+ 20 23	7 26 "	2 54.7 "	10 23 "
25	4 33.1	+ 20 26	6 49 "	2 17.8 "	9 46 "

THE SUN.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Apr. 5	0 59.6	+ 6 22	5 34 A. M.	12 02.6 P. M.	6 31 P. M.
15	1 36.3	+ 10 02	5 16 "	11 59.9 "	6 43 "
25	2 13.7	+ 13 26	5 00 "	11 57.8 "	6 56 "

Phases and Aspects of the Moon.

		d	h m	
Full Moon	Apr.	1	1 18	A. M.
Apogee	"	5	12 30	P. M.
Last Quarter	"	9	5 35	A. M.
New Moon	"	16	8 34	"
Perigee	"	17	3 54	P. M.
First Quarter	"	22	11 26	"
Full Moon	"	30	5 23	"

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A. ......$0^h\ 52^m\ 32^s$
Decl. ......+81° 17′
Period......$2d\ 11^h 50^m$

1893.		
Apr.	3	7 A. M.
	5	7 P. M.
	8	7 A. M.
	10	7 P. M.
	13	7 A. M.
	15	7 P. M.
	18	6 A. M.
	20	6 P. M.
	23	6 A. M.
	25	6 P. M.
	28	6 A. M.
	30	6 P. M.

S. CANCRI.

R. A. ......$8^h\ 37^m\ 39^s$
Decl. ......+ 19° 26′
Period......$9d\ 11^h 38^m$

Apr.	18	2 A. M.

S ANTLIÆ.

R. A. ......$9^h\ 27^m\ 30^s$
Decl. ......—28° 09′
Period...... $7^h\ 47^m$

Apr.	1	8 P. M.
	2	7 "
	3	7 "
	4	6 "
	6	midn.
	7	midn.
	8	11 P. M.

S ANTLIÆ CONT.

Apr.	9	10 P. M.
	10	10 P. M.
	11	9 "
	12	8 "
	13	8 "
	14	7 "
	18	midn.
	19	midn.
	20	11 P. M.
	21	10 "
	22	10 "
	23	9 "
	24	8 "
	25	8 "
	26	7 "
	30	midn.

δ LIBRÆ.

R. A. ......$14^h\ 55^m\ 06^s$
Decl. ......— 8° 05′
Period......$2d\ 7^h\ 51^m$

Apr.	7	2 A. M.
	14	1 "
	21	1 "
	27	midn.

U CORONÆ.

R. A. ......$15^h\ 13^m\ 43^s$
Decl. ......+ 32° 03′
Period......$3d\ 10^h\ 51^m$

Apr.	3	5 A. M.
	10	3 "
	16	midn.

U CORONÆ CONT.

Apr.	23	10 P. M.
	30	8 "

U OPHIUCHI.

R. A. ......$17^h\ 10^m\ 56^s$
Decl. ......+ 1° 20′
Period...... $0d\ 20^h\ 8^m$

Apr.	2	6 A. M.
	3	2 "
	7	7 "
	8	3 "
	13	4 "
	13	midn.
	18	4 A. M.
	19	1 "
	23	5 "
	24	1 "
	28	6 "
	29	2 "

λ CYGNI.

R. A. ......$20^h\ 47^m\ 40^s$
Decl. ......+ 34° 15′
Period......$1d\ 11^h 57^m$

Apr.	5	7 A. M.
	8	7 "
	11	7 "
	14	7 "
	17	7 "
	20	7 "
	23	7 "
	26	7 "
	29	7 "

Occultations Visible at Washington.

Date 1893.		Star's Name.	Magnitude.	IMMERSION Washington M. T.		Angle f'm N pt.	EMERSION Washington M. T.		Angle f'm N pt.	Duration	
				h	m	°	h	m	°	h	m
Apr.	1	*h* Virginis	5.8	13	07	178	13	57	257	0	50
	4	B.A.C. 5254	5.8	13	02	213	13	57	251	0	55
	23	B.A.C. 3138	6.3	3	45	159	5	04	295	1	19
	23	B.A.C. 3206	6.3	11	03	72	12	08	290	1	00

New Asteroids.—Five new asteroids were discovered photographically in January. They will be designated by the letters of the alphabet until the end of the year, when probably the consecutive numbering will be given only to those whose orbits have been determined.

1893.	By	Photo. at	Date.	Mag.	First Observations. Gr. M. T.			R. A.			Decl.			
						h	m	h	m	s		°	′	″
A	Charlois	Nice	Jan. 17	9.0	Jan. 18	8	01	8	08	59.3	+	9	29	12
B	Wolf	Heidelberg	Jan. 12	13.0	Jan. 12	12	15	8	15	31.9	+	14	51	57
C	Wolf	Heidelberg	Jan. 16	13.0	Jan. 16	12	47	9	14.3		+	17	44	
D	Charlois	Nice	Jan. 18	12.5	Jan. 20	8	05	8	19	15.4	+	16	12	29
E	Charlois	Nice	Jan. 20	12.5	Jan. 21	8	20	8	28	03.7	+	25	01	56

Occultation of Jupiter, Jan. 23, 1893.—I duly observed the occultation of Jupiter which occurred on the night of January 23, 1893. The night was severely cold and clear and definition remarkably good. The dark limb of the Moon, clear, sharp and well defined, touched satellite IV at $8^h\ 49^m\ 35^s$ E. S. T., which appeared to glide on to the dark limb for a short distance and then slowly disappear. I saw it distinctly projected in the dark body of the Moon. Satellites I, II, and III, also occulted, apparently gradually disappeared at the limb without appearing to glide on, or within it, as did IV. The limb of the Moon at 9^h touched the planet and was very steady and well defined as it passed over it. As the limb approached the planet it seemed to become *concave* at and near the point of contact and remained so until contact took place when instantly it assumed its normal shape.

I failed to observe the dark line on the planet along the edge of the Moon, mentioned by some observers though the limb and planet were as steady, distinct, and sharp as an engraving. The emersion I did not observe. The instrument used was my 5-in. Clark refractor, power 110.

I delayed sending this report as it was so near the time for issuing February number that if you cared to insert it, it would be too late. E. S. MARTIN.

Wilmington, N. C., Feb. 9, 1893.

Dr. Otto Tetens has recently sent us his inaugural dissertation presented for the doctor's degree at the University of Kiel. It is an investigation of the rate of the standard clock of the Bothkamp Observatory. From observations during 1890 and 1891 he finds that the rate of the clock can be closely represented during long periods of time by a rate-formula including terms involving the time, temperature and barometric pressure. He gives for July 31, 1891 the formula

$$\begin{aligned}\text{Daily rate} = &+ 0^s.0931 - 0^s.000209\,(T - 1891\text{ July }31.5)\\ &- 0^s.0442\,(t - 10^\circ\,C) + 0^s.0153\,(b - 760\text{ mm}),\end{aligned}$$

in which T is the date, t the temperature (centigrade) and b the barometer reading. H. C. W.

COMET NOTES.

No new comets have been discovered this year, up to the date of this writing. All the comets of last year are receding and growing fainter. Swift's comet is still visible in a 16-inch telescope but too faint for accurate observation. Brooks' comet *d* 1892 is too far south for observation in this latitude. Brooks' *g* 1892 will be difficult during March and April because of its nearness to the Sun as well as its faintness. The same will be true of Holmes' comet unless another outburst like that in January should occur. The change in this comet since Jan. 16 has been an almost exact duplication of its behavior in November. It has expanded to about 10′ in diameter through the head, with a tail about 30′ long. It is, however, now a difficult object to observe micrometrically because there is no definite nucleus. The last glimpse of the nucleus which we obtained with the 16-inch was on Feb. 4, when at moments we could see a very small bright point of about the 14th magnitude.

Regarding the outburst of Holmes' comet in January, Professor C. A. Young writes under date Feb. 4, that Mr. Reed observed the comet with the 9-inch telescope and succeeded in getting its spectrum purely continuous. He thinks the *asteroid collision* theory of its origin extremely improbable, but queries whether if the asteroids were formed by a series of "explosions," breaking up first an original planet and afterwards the pieces from it, this might not be an event of that sort—an eruption from an asteroid.

The following note from Professor Stone's assistant at the Leander McCormick Observatory, was received too late for our last issue.

The Outburst of Light in Holmes' Comet.—I observed comet Homes' on Jan. 13, and found the nucleus very faint and nebulosity diffuse extending over an area having a diameter of about 25′. It was much fainter and more hazy than on the 12th. Clouds interfered until the 16th when on directing the telescope to position given by ephemeris there appeared what seemed to be a bright star in a fog. The center was of a reddish yellowish color and the circular fuzz surrounding it about 30″ in diameter. Clouds came up before a micrometric measure could be made. I could not locate the body in any nebula catalogue so concluded that it was a star behind the nebulous envelope of the comet. Its identity was concealed by the fact that comet Holmes' is receding from the Sun and had been growing fainter. Micrometric measurements of the body on the 17th proved it to have the position and motion of comet Holmes. Brightness of the nucleus estimated at 9.5 mag. Snow storm on the 18th forbade observations. On the 19th the comet showed greater condensation and the nucleus was at least half a magnitude brighter than on the 17th. There was a marked change in the comet's color, it being decidedly bluish. Visible in the finders of the telescope and I saw it with the naked eye. On the 20th the nucleus was fully as bright as before, though the comet as a whole was fainter. Circular nebula around the nucleus not quite as large, about 25″ in diameter. The nucleus was as well defined as 9 mag. stars near and appeared like a star in a nebula. Color still bluish, as noted on the 19th. On the 21st the nucleus was larger, diameter about twice as great as before, but there was no diminution in the apparent brightness of the comet notwithstanding the moonlight. I used the 26-inch and a power of 175. E. O. LOVETT.

Leander McCormick Observatory, Jan. 21, 1893.

Holmes' Comet.—The following few notes on the appearance of the remarkable Holmes' Comet were made with a 3-inch telescope, (objective by Brashear, of Jena glass).

Noticing in the press dispatches of January 18th, that new changes had taken place in this comet, the same evening I looked up its position and came across what appeared to be a wide double star of about 7th and 8th magnitudes; on closer inspection the larger star appeared hazy, and on applying a higher power discovered that the object was nebulous and nearly circular, with a brighter condensation towards the center. On the 21st, it had greatly increased in size and with a low power appeared as a beautiful large, bright planetary nebula, brighter towards the center. Owing to unfavorable weather, another observation was not obtained until the evening of February 7th, when the appearance of the comet was entirely changed, it had now become much larger and quite diffuse. On the 10th, it appeared still larger but fainter. On the 12th, it was somewhat fainter and seen best with a low power, with a power of about 60 it was very difficult to observe. It had apparently decreased in size on the 14th, but was too near B Trianguli (which was in the same field of view) to estimate its brightness. On the 18th and 19th, it was apparently diminishing in size, and somewhat oval in appearance, but even with a very low power it was hard to determine the extent of the nebulosity; with a power of about 60 it was an exceedingly difficult object seen only by " oblique vision " as a mere vapor on the dark background of the sky.

Alta, Iowa, Feb. 20th, 1893. DAVID E. HADDEN.

Biela's Comet.—A few words regarding this comet may not be out of place. Persons who expected a collision between the earth and this comet last fall, had not carefully noted the dates of its perihelion passage. The three times of this event of which the dates are before me, are those of November 17 (27), 1832; February 11, 1846; and September 23, 1852. The interval between the last two dates is 6 years, 7 months and 12 days. The preceding interval is just double the time. But Robinson, quoting Littrow, gives November 27, as indicated above, but this may be an error of the types.

In Young's Astronomy you find this: "On November 27, 1872, just as the earth was passing the track of the lost comet, she encountered a wonderful meteoric shower." Now the comet was due at perihelion on the 29th of the preceding July,—and had passed the point of nearest approach to the earth's orbit about ten weeks earlier,—in the middle of May. Wherefore six months after the body of the comet was due at the collision point, there was a "wonderful meteoric shower." There can be but little doubt that these meteors are the pulverized products of its disintegration,"—six months behind the fore-front of the system.

Similarly in 1892, the comet, if an entire body, should have passed the danger point about the middle of last March, and the perihelion about the 5th of June,—8 months afterwards, on the 23rd of November, there was another good display of meteors. It is well known that any disturbance of the orbit by any of the planets, would pull the node westward. And I think it positively shown by the display of the 23rd, not only that the comet is disintegrated, but also that the fragments are scattered along the orbit for about one-fourth of its whole extent, or about 500 million miles. Supposing the comet's period to be as above given, but that the node has retrograded 4 days, then the comet will pass the danger point about two weeks in advance of the earth in November, 1898; but will be two weeks late in 1931; yet if the node should retrograde meanwhile so that the comet should reach the node two weeks earlier than the regular rate would demand, then the comet and the earth will come into direct collision. Timorus people will have ample time to make way with themselves long before the clash comes; other kinds may turn out and see the grand display. R. W. M.

Ephemeris of Comet 1893 I (Brooks Nov. 19, 1892).

[Continued from page 185].

Gr. Midn.		App. R. A.			App. Decl.		log *r*	log. Δ	Br.
		h	m	s	°	′			
Mar.	5	0	42	38	+21	34.6	0.1737	0.3380	0.56
	6		43	36		21.5			
	7		44	34	21	08.8			
	8		45	31	20	56.4			
	9		46	27		44.4	0.1842	0.3564	0.48
	10		47	22		32.7			
	11		48	17		21.4			
	12		49	11	20	10.4			
	13		50	05	19	59.8	0.1947	0.3732	0.42
	14		50	58		49.4			
	15		51	50		39.3			
	16		52	41		29.5			
	17		53	32		19.9	0.2051	0.3884	0.38
	18		54	22		10.6			
	19		55	12	19	01.5			
	20		56	01	18	52.6			
	21		56	50		44.0	0.2157	0.4022	0.34
	22		57	38		35.6			
	23		58	25		27.4			
	24		59	12		19.4			
	25	0	59	59		11.5	0.2261	0.4146	0.30
	26	1	00	45	18	03.8			
	27		01	31	17	56.4			
	28		02	16		49.1			
	29		03	01		41.9	0.2365	0.4258	0.27
	30		03	45		34.9			
	31		04	29		28.0			
Apr.	1		05	13		21.3			
	2		05	56		14.7	0.2468	0.4358	0.25
Apr.	3		06	39		8.2			
	4		07	21	17	1.8			
	5		08	03	16	55.5			
	6		08	44		49.4	0.2570	0.4448	0.23
	7		09	26		43.4			
	8		10	05		37.4			
	9		10	45		31.5			
	10		11	25		25.7	0.2670	0.4526	0.21
	11		12	04		20.0			
	12		12	43		14.5			
	13		13	22		09.0			
	14	1	14	00	+16	03.6	0.2770	0.4596	0.20

A Remarkable Meteor.—December 9th, 1892, about 9 o'clock P. M., a remarkable and magnificent meteor shot out from the constellation Andromeda and moved slowly and majestically towards the northeastern point of the horizon. When first seen here, it was about the size and color of an orange, but rapidly increased in brilliancy and size until before it disappeared below the horizon it was of the apparent size of the full Moon and was surrounded by a mass of glowing vapor which further increased its size to that of the head of a flour barrel. It soon became intensely brilliant, flashing at times a greenish blue light, throwing off sparks "fast and furiously," and left behind it a dense stream of vapor 30° to 40° in length.

A gentleman who was at Jacksonville, N. C. (about 50 miles N. E. from Wilmington), and saw it, gave me the same description of the meteor in every particular. To-day I learned that the same meteor was observed at Washington, N. C. (about 125 miles N. by E. from this city). The writer says: "We saw the meteor which passed over, going in a northeastwardly direction. It did not seem to be very high and was going at a rapid rate. It was about the size of a man's head with a tail of some length and small pieces were flying off and it was a beautiful sight."

It must have passed to sea about the neighborhood of Norfolk, Va., and probably fell into the ocean. E. S. MARTIN.

NEWS AND NOTES.

This number is sent only to such subscribers as have renewed, or ordered a continuance of their subscriptions for the current year.

The contents of the February number of this journal will be found on page 288. It is repeated for the information of readers who may not have seen that number.

It is particularly requested of all correspondents that articles intended for publication should reach this office on or before the 15th of the month preceding that of publication. News items or paragraph notices should not be later than the 20th, that mailing may regularly come on the last day of the month.

Professor Rowland's List of Standard Wave-Lengths.—We have already in type a table of more than 20 pages of standard wave-lengths of various substances, recently prepared by Professor Rowland of Johns Hopkins University, Baltimore. It is scarcely necessary to add that this contribution to Astronomy will be of world-wide use as a standard of reference.

E. E. Barnard at Goodsell Observatory.—The visit of E. E. Barnard and wife at Goodsell Observatory of Carleton College, on February 21st, was one of the most enjoyable and instructive occasions in the history of the Observatory. During the forenoon of that day, Mr. Barnard spoke to groups of students at the Library of the Observatory almost continuously. He had for exhibition 35 large photographic plates, which were intended as illustrations of some of the lines of his recent work in celestial photography at the Lick Observatory. The themes were different portions of the Galaxy, showing wonderful cloud masses of stars, star groups, and star configurations in great variety. His descriptions of these various features plainly showed his intimate acquaintance with them by the aid of the telescope and the photographic plate. His views of the great telescope, the buildings of the Lick Observatory and adjoining mountain scenery were also greatly enjoyed. In the afternoon Mr. Barnard continued the exhibition of his photographs to increasing numbers of visitors including a goodly number of residents from the city. At four o'clock, without a moment's time for preparation, he kindly accepted the invitation of professors to speak at the College Chapel before the body of students and friends from the city. He was asked to speak on "Jupiter and his Satellites." He talked for an hour, in a clear and very ready manner, giving a résumé of his observations concerning the chief markings of the planet's surface for a period of fourteen years. His modest references to the discovery of the fifth satellite of this planet was generally noticed and commented on, but the brilliancy of the discovery lost nothing through Mr. Barnard's modesty, which was universally admired, foi genius and a noble character could not thus be hidden.

Mr. Barnard went from Northfield to Chicago to visit his old friend, Mr. Burnham and others. From this point he will visit his former home in Nashville, Tennessee. Then, about April 1st he will sail for Europe. His leave of absence from Lick Observatory is for 6 months or more as he may desire. The Board of Regents of the University of California evidently appreciate Mr. Barnard's services, for they have raised his salary, propose to build for him a house on Mt. Hamilton and have given him a generous vacation.

It will interest our readers to notice that Mr. Barnard has become one of the associate editors of this Journal. His work will have prominent place in these pages in the future.

The Peters' Star Catalogue Decision.—It will be remembered that the famous Star Catalogue case, Peters vs. Borst, which was tried four years ago was appealed by the defendant. The decision on this appeal, handed down last fall, is now before me. It is written by Justice Hardin, Justice Merwin concurring. After reviewing the main points of the case and sustaining the rulings of the Court upon the trial, the decision concludes:

"Upon a careful examination of the appeal book we have not found any strong grounds to believe that the merits have not been fully and fairly passed upon by the trial court, and we discover nothing in the case to indicate that a new trial would be more likely to result in a more just conclusion than the one reached at the circuit. Our conclusion is that the decision at the circuit should remain. Judgment affirmed with costs." J. G. PORTER.

Publications of the Observatory at Berlin.—The sixth volume of the new series of publications of the Observatory at Berlin has recently been received. It contains the account by Professor V. Knorre, of a new method of measurement of double stars with a double-refracting prism micrometer, proposed by Dr. V. Wellmann, together with Dr. M. Brendel and Professor V. Knorre. There are appended observations of double stars, according to the new method, by Professor Knorre, Mr. T. J. J. See and Dr. Wellmann. There are also papers by Dr. Brendel on the refraction of light in prisms of uniaxial crystal and their use for micrometrical measurement, and by Dr. Wellmann on the influence of temperature on the measures made with double refracting prisms.

Publications of the Observatory at Karlsruhe.—The fourth volume of the publications of this Observatory, edited by Dr. W. Valentiner has recently come to hand. It contains the detailed observations and mean results of meridian circle observations of something over one thousand stars in the zone from the equator to −10° declination. There are also papers by Dr. Boy Matthiessen on measures of the star-cluster G. C 1119, and by Dr. Friedrich Ristenpart on the constant of precession and the motion of the solar system. The results obtained in the last paper agree, in general, with the results obtained by other investigators, in putting the apex of the solar way at about R. A. 280° and Decl. + 30°. The author shows however that quite different results may be obtained by different methods of treating the same data. He finds for the annual translatory velocity of the solar system about 5.41 radii of the earth's orbit.

Micrometrical Measures of Some Double Stars with New Companions, and of Five New Pairs.—(Paper read before The Astronomical and Physical Society of Toronto, 24th January, 1893.) The following new companions have been discovered during a revision of some stars for the new edition of "Celestial Objects." The telescope used is the 17¼-in. reflector; the micrometer was made by Troughton & Sims. The mean measures only are given. The stars are arranged in their order of constellations. The R. A. and Decl. are for 1900. The magnitudes are on Struve's scale. The work was done from September to December, 1892.

No.	Star.	R. A.		Decl.		P.	D.	Mags.	*n*.	
		h	m	°	′	°	″			
1	Sigma 994	5	52.8	37	14	220.9	9.13	7.2......12.0	1	AC.
2	P III .97	3	34.5	59	39	96.2	18.68	6.0......13.8	1	AB.
						302.4	34.65	......13.0	1	AC.
3	Dembowski	4	32.0	53	17	69.0	18.04	8.5......12.5	3	AC.
4	Beta Camelop	4	54.5	60	18	167.4	14.81	7.0......11.5	2	BC.
5	Cassiop	0	25.6	56	14	113.3	6.36	8.2...... 8.5	3	AB.
6	Anon	0	29.4	56	3	158.5	8.66	8 9	3	Yellow: blue.
7	Anon	0	49.7	57	15	116.3	4.86	9.6...... 9.8	2	AB.
8	Sigma 182	1	49.3	60	48	75.2	29.9	7.0......13.5	2	AC.
9	Sigma 306	2	43.4	60	1	74.3	17.02	7.1......13.8	2	AC.
						112.0	19.21	......13.5	2	AD.
						105.6	27.40	......13.0	2	AE.
10	Anon	23	56.7	59	26	289.3	10.13	8 9	..	Yellow: blue.
11	Webb	19	46.8	44	54	327.9	31.54	8.0...... 9.0	5	AB.
						138.8	7.68	......11.5	3	AC.
12	Anon	20	45.2	32	51	245.6	9.61	8.7...... 9.0	3	AB very red: blue.
						141.1	17.86	......10.0	3	AC.
13	59 Cygni	20	56.6	47	8	224.1	37.09	4.7......13.5	3	AD.
14	H. V. 66	7	21.7	22	21	23.9	11.31	7.0......13.5	1	
15	Sigma 2916	22	27.0	40	42	118.0	16.56	8.0......13.8	3	BD.
16	8 Lacertæ	22	31.4	39	6	200 ±	9.95	8.0......13.8	3	Dd.
17	Sigma 446	3	41.9	52	21	42.7	11.59	7 ......12.5	1	AC.

No. 3. Place of 2 Cameli. No. 9 Dembowski measured a more distant *comes*, there are three others still more distant.

Where the stars are below 12.5, the measures have been made with great difficulty and show considerable differences both in distance and angle. The mirror has not been silvered for four years and so the faint stars are difficult objects with it.

T. E. ESPIN.

Towlaw, Darlington, England, 1892, Jan. 6.

In looking over the foregoing list of distant companions, I have made the following notes:

No. 1. If this is Σ 994, as it appears to be from the declination, the hour of R. A. should be 6 and not 5 as given in the MS. In Struve this is a wide pair (25″) of bright stars, and therefore the distant star measured above should be called C, according to the usual method of lettering companions in the order of their distances from the primary. The bright pair is also H 3286, and Herschel notes, "two small stars near," but this probably has reference to stars still more distant than B.

No. 3. The principal star of Dembowski's pair is O. Arg. N. 5001. He did not see the 18″ star measured by Mr. Espin, but connected a distant, wide triple with A of this pair.

No. 4. South measured a very remote 9m star at a distance of 80″ from the primary, and C is a faint star near that. There has been no sensible change in the relative positions of A and B, and therefore the proper motion may be assumed to be very small.

No. 9. The most distant star, E, was measured by Dembowski in 1867, P = 156°.9; D = 27″.48. The discrepancy in the position-angle will be noticed.

Evidently there is a clerical error in one or the other. As Dembowski measured it on a single night only, it is probable that Mr. Espin's angle is correct. The other stars C and D have not been measured before. Dembowski called the magnitude of E 11.5.

No. 10. This star is O. Arg. N. 26323. It is noted as "duplex" in that catalogue. Many years ago with the 6-inch I looked up all of the stars having this note attached to them in Argelander. This object was estimated, 290° : 10″ : 9.....9.5 (1875). As all of these pairs were very wide or faint, I did not follow them up with the micrometer.

With so large an aperture, assuming that the definition is what would be expected in a much smaller refractor, it seems strange that Mr. Espin should not have picked up some pairs close enough to make physical systems. An aperture of this size should be sufficient for the discovery of pairs down to 0″.3. This, however, would depend entirely upon the definition of the mirror, the light power being of very little importance. S. W. B.

Astronomical Journal Prizes.—By an oversight the following important announcement was omitted from our last number. It is taken from *The Astronomical Journal*, No. 284.

"A gentleman, earnestly interested in the development and progress of astronomy in his native land, has authorized this Journal to offer two prizes, for resident citizens of the United States.

"He expresses the hope that it may be possible to offer similar prizes in subsequent years, although only two are proposed at present, the requisite amount for these having been placed at the editor's disposal.

"They will be known as *Astronomical Journal Prizes*, and will be given either in money, or in the form of a suitable gold medal of the value of two hundred dollars, with the remainder, if any, in money, at the option of the recipient.

"The awards will be made by a commission of three judges, to be selected from American astronomers, and their names to be announced in due time.

"The prizes now offered are for researches tending to advance our knowledge of cometary orbits, and are these.

I.

"For the observer making the best series of determinations of the positions of comets during the year ending the thirty-first of March, 1894, a prize of two hundred dollars. The conditions to be considered in the award will be the accuracy of measurement and reduction, the number of the observations and their judicious distribution along the geocentric paths, and the promptitude of their publication. To equalize the claims of observers, due allowance will be made for the different optical powers of the telescopes used. Also, since there seems to have been a tendency to neglect such comets as are observable only in the morning, regard is to be had in the award, to the especial usefulness of observations made at inconvenient hours.

II.

"For the best discussion of the path of a periodic comet, with due regard to its perturbations, of the kind ordinarily known as the definitive determination of the orbit, a prize of four hundred dollars. The investigation must, however, have been made within the two years next preceding 1894, Sept. 1, and the manuscript (which will be returned to the author) transmitted, not later than that date, to some one of the judges.

"In these awards it will be left to the discretion of the judges to decide whether in case of uncertainty on account of nearly equal claims of two candidates, either of the prizes ought to be divided. Also, in case that either award should not, in their opinion, be fully justified, they will be authorized to withhold the same; in which event it will be offered again, under the same conditions, for the next ensuing year.

"Should similar prizes be offered in the coming year, it is intended that one of them shall be for the best series of determinations of maxima and minima of variable stars during the years 1893 and 1894."

In *Astronomical Journal* No. 288 we find the following additional announcements:

"The commission of Judges designated for the award of these prizes consists of Messrs. Asaph Hall, Seth C. Chandler and Lewis Boss

"Two additional prizes are hereby offered, for the year 1895, subject to the same conditions as were prescribed for those of the year 1894.

I.

"For the observer making, by Argelander's method, the best series of determinations of maxima and minima of variable stars during the two years ending 1895, March 31, a prize of two hundred dollars. A principal basis for the award is to be the extent to which the determinations will contribute to our better knowledge of the periodic variables, by furnishing the largest number of maxima and minima of the largest number of stars, having especial regard to stars whose characteristics are at present not very well known.

II.

"For the most thorough discussion of the theory of the rotation of the Earth with reference to the recently discovered variations of latitude, a prize of four hundred dollars. The manuscript (which will be returned to the author) is to be transmitted to some one of the judges, not later than 1895, March 31."

These announcements are certainly gratifying to both professional and amateur astronomers. They ought to result in stimulating a great deal of useful effort and without doubt some important results. There is perhaps no lack, in this country, of observers of comets, but it is unfortunately true that many of the observations have much less value than they would have if they were made more carefully and at judiciously chosen times. There is a notable lack, in this country, of mathematical investigators in astronomical lines. The great bulk of the work of definitive determination of orbits of comets and planets has been done in Germany and France. Two or three names only keep up our reputation in connection with the theories of the Moon and Earth. It is therefore to be hoped that there may be many competitors for the prizes II of 1894 and 1895.

The first prize for 1895 is one which should attract especially the attention of amateurs, since the observations require only a good eye, a star-atlas and catalogue of star-magnitudes, and a moderate amount of perseverance. An opera-glass is a useful aid in variable star observations, but it is not necessary, many very valuable results having been obtained with only the apparatus mentioned above. Of course only one can receive the prize, but each observer is liable to be made famous by the discovery of new variable and temporary stars.

Astronomical Clock Correction.—In the *Monthly Notices*, No. 1, Vol. LIII, will be found a paper on the "Probable Error of the Clock Correction, when both the clock rate and the instrumental constants are found by the least squares solution of a single night's observations," by the Rev. John T. Hedrick, S. J., Georgetown College Observatory, District of Columbia. A brief summary at the close of the paper is given, as follows:

The epoch of the clock correction of maximum weight, or minimum probable error, is not, in general, the mean of the times of observation when, besides the constant clock correction and the clock rate, instrumental constants are also determined from observations.

If these quantities are found by a least squares solution, this epoch is before or after the epoch assumed for the constant clock correction, by an interval which is the quotient of the co-efficient of the constant clock correction in the normal equation for the rate by its co-efficient in its own normal equation, after the elimination of the other unknowns.

If we count from this epoch, the probable error of the clock correction at any other time is what it would be if the constant correction and the rate were independently observed quantities—that is, its square is the sum of the square of the probable error at this epoch and the product of the square of the probable error of the rate into the square of the interval from this epoch Hence the square of the probable error of the clock correction, at this epoch, is equal to the square of the probable error of the clock correction, at the assumed epoch, minus the product of the square of the probable error of the rate into the square of the interval between the two epochs.

Chicago Academy of Sciences, Section of Mathematics and Astronomy.—The regular monthly meeting was held on Tuesday, Feb. 7, at the Chicago Athenæum. Professor Hough in the chair. Officers for 1893 were elected as follows:

Chairman, George W. Hough; Recorder, George E. Hale; Executive Committee, S. W. Burnham, E. H. Moore, G. A. Douglass.

Dr. T. J. J. See, of the University of Chicago, presented a paper on the "Evolution of the Double Star Systems," which was illustrated by means of figures and lantern projections. It contained a *resume* of the researches recently published in his *Inaugural Dissertation* at the University of Berlin. The speaker, in presenting the paper, reviewed the successive steps in the progress of Cosmogony made by Laplace, Thompson, and Darwin, and pointed out the importance of the work of each. Laplace's hypothesis of ring-formation, though mathematically sound, was seldom realized in nature, as he inferred from the well known rarity of ring-nebulæ, whilst the great abundance of double nebulæ and double stars would seem to indicate that the general process of division was a sort of gravitational "fission," as is also confirmed by the mathematical researches of Darwin and Poincaré on the figures of equilibrium of rotating masses of fluid.

Dr. See explained how tidal friction could increase the eccentricities of the double star orbits, and showed that the theory advanced in his *Inaugural Dissertation* explained the leading peculiarities of the double star systems, viz.:—

(1). The large eccentricities of the orbits.

(2). The large mass-ratios of the component bodies. Adjourned.

GEORGE E. HALE, Recorder.

New York Academy of Sciences: Astronomical Section.—*Minutes of the Meeting, 1893, January 9.*—The Section was called to order at 8:15 P. M., Professor Rees in the chair. A paper was read by Mr. Harold Jacoby on "The parallaxes of μ and ϑ Cassiopeiæ, deduced from Rutherfurd photographic measures. The results obtained are the following:

Parrallax of μ Cassiopeiæ $= + 0''.275 \pm 0''.024$.

Parrallax of ϑ Cassiopeiæ $= + 0''.232 \pm 0''.067$.

The paper will appear in the annals of the Academy.

Professor Rees made a few remarks on the above paper, after which Professor

Geo. E. Hale, of the University of Chicago, described some of his recent investigations in solar physics. Professor Hale showed lantern slides of the apparatus used by him at the Kenwood Observatory, and some very remarkable photographs of prominences and faculæ, which he has obtained in full sunshine. Adjourned.
HAROLD JACOBY,
Secretary Astronomical Section.

New York Academy of Sciences, Astronomical Section.—*Minutes of the Meeting 1893 Feb. 6th.*—The Astronomical Section was called to order at 8:15 P. M., Professor Rees in the chair. The following paper was read: "A Theory of the Formation of Lunar Craters," by G. K. Gilbert. The theory agrees with the meteoric theories of Proctor, Meydenbauer and others in that it ascribes the craters to the impact of bodies colliding with the moon. It differs as to the previous history of the incident bodies. It postulates as the antecedent of the moon an annulus of many small bodies surrounding and revolving about the earth as does the ring of Saturn about the planet. The components of this ring afterward segregated so as to constitute a smaller number of larger bodies, and finally a single body, the moon. The craters of the moon's surface, large and small, are the impact scars of those minor aggregates which were last captured by the moon.

After the moon had acquired approximately its present mass the velocity of impact for bodies of the system was about 7700 feet per second. The energy due to this velocity, if converted into heat, was more than sufficient to fuse the colliding body, assuming that body to have the specific heat and fusing point of diabase. The impacts of small bodies seem to have produced deformation without fusion; but in the impacts of larger bodies more energy was applied to each unit of surface, and parts of projectile and target were fused, producing the level plains of the larger craters. The recoil of the liquefied and softened rock toward the center produced the central hill characteristic of lunar craters. The corrugated rim of the typical lunar crater is due to outward thrust; the inward facing cliff overlooking the inner slope, and the broken terraces below it, are due to land slips, a part of the rim falling back into the fused tract.

The round *maria*, such as *M. Crisium* and *M. Serenitatis*, are regarded as large craters, and the Caucasus-Appenine-Carpathian mountain chain as the remnant of a crater rim with a radius of 400 miles.

Certain parts of the surface are observed to be sculptured by an agency acting along lines which, for each locality, are nearly parallel. Grooves are plowed, crater rims are notched, and ridged additions appear to have been made to the surface. The same districts have been flooded by liquid and viscous matter, diminishing the depth of the larger craters, obliterating the small craters, partly filling cracks (rills), and afterward solidifying. In some low-lying districts the more liquid part of this matter collected, producing plains of the second order of magnitude and even *maria*. The lines of sculpture of these districts radiate from a point in the *Mare Imbrium*. It is believed that the collision of a very large moonlet at this place, under circumstances causing much fusion, hurled a deluge of molten and fragmental rock in all directions, flooding and partially remodeling a fourth part of the visible face of the moon. The central tract of the moon lies within the flooded area, and to this fact is ascribed the often noted contrast between its topography and that of the "honeycomb" district about the south pole.

The paper is to be printed in full in the Bulletin of the Philosophical Society of Washington.

After remarks by Dr. Bolton, Mr. Jacoby, and Professor Rees, the Section adjourned.
HAROLD JACOBY, Sec'y Astron. Section.

Camden Astronomical Society.—At the regular meetings of this Society held during the year 1892 the following papers were read,

The Camera in Astronomy, by T. Worcester Worrell.
Tidal Friction, by Herbert Whittaker.
The Theory of the Spectroscope, by E. E. Read, Jr.
Lightning Photography, by W. R. Jennings.
An absolute point for Right Ascensions, by E. F. Moody.
The light of Jupiter, by R. M. Luther, D. D.

Astronomical and Physical Society of Toronto, Ca.—The annual meeting of the Astronomical and Physical Society of Toronto, held in January last, considered various topics of general interest. The following extract from a communication to the society from Professor W. H. Pickering is timely:

"The nomenclature upon Mars is certainly in very bad shape, and I should be glad to join in any movement to improve it. I feel the more interest in the matter as I hope to publish a map of the planet, showing a number of features not previously located. Personally, I find Professor Schiaparelli's names often very long and very hard to remember. The English nomenclature, in that respect, seems to me much superior. On the other hand, if that is retained, it seems to me the same difficulty will arise in the future that now exists in the case of the moon—very inconspicuous and uninteresting peaks commemorate great names like Herschel, Le Verrier, and Encke, while much more important summits are named after mediocre men who lived long before them. Moreover, it seems to me a little presumptuous to foist any man's name upon a grand natural object. I am quite prepared in my work to adopt any plan of nomenclature that meets with general acceptance."

The principal address at this meeting was that given by Dr. Otto Hahn on "Meteorites" in connection with which he exhibited a number of micro-photographs and specimens of meteors. He discussed the chemical and physical nature of the meteorite, and maintained that they are not broken planets, but that most of them floating in space are of the same general shape and constitution, as when found. Dr. Hahn is said to have a large collection of meteorites and that he has given considerable attention to the study of them. He prepared his own slides and showed the details explained by means of several microscopes.

Two other meetings of this society have been reported which show it to be very prosperous financially, and also indicate that it is fully maintaining its standard for good and useful work. As a means of popular instruction in science nothing can take the place of such a society.

BOOK NOTICES.

Cours d'Astronomie a l'usage des etudiants des facultes des sciences par B. Baillaud, director de l'observatoire de Toulouse. Premiere partie, Quelques théories applicable a l'étude des sciences experimental, Paris, 1893.

The author begins with the principles of probabilities and their application to the theory of errors of observation, which are needed at the outset by a student in practical astronomy. He then takes up the study of optical instruments in a very complete manner, giving first the general theories then their special application to the principal astronomical instruments. The last chapters treat of the measurement of angles and arcs, methods of calculation and the problem of interpolation.

The second part, not yet published, is to be devoted to astronomy itself, including the determination of orbits, of planets and comets, the theory of the Moon and the calculation of perturbations.

CONTENTS FOR FEBRUARY.

PUBLISHER'S NOTICES.

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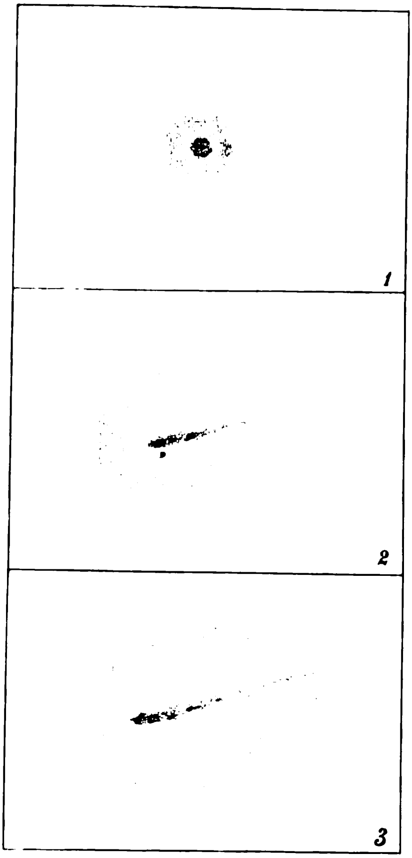
PLATE XIX.



HOLMES'S COMET.

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W. F. DENNING.

Astronomy and Astro-Physics.

VOL. XII, No. 4. APRIL, 1893. WHOLE No. 114.

General Astronomy.

EVOLUTION OF THE DOUBLE-STAR SYTSEMS.[*]

T. J. J. SEE.

Sound cosmogonic speculation begins with Kant, who was the first of modern philosophers to advance a definite mechanical explanation of the formation of the heavenly bodies,[†] and particularly of the bodies composing the solar system. The views of Kant, however, do not seem to have received much scientific recognition until after Laplace's independent formulation, in more exact mathematical terms,[‡] of a similar explanation of the origin of the planetary system, based upon remarkable phenomena observed in the motions of the planets and satellites, and known as the Nebular Hypothesis. Partly on account of the overwhelming[§] argument of Laplace in favor of a *natural* or *mechanical* explanation[‖] of the origin of the planetary system, and the sound dynamical conceptions underlying the great geometer's hypothesis, and partly on account of the keen interest and speculation arising out of Sir Wm. Herschel's epoch-making investigations of the nebulæ, the Nebular Hypothesis was soon accepted by astronomers as an explanation entitled to scientific belief. The classic researches of Sir John Herschel tended still further to establish confidence in Laplace's view of the nebular origin of the heavenly bodies; but when Lord Rosse's great Reflector showed the discontinuous nature of some of the objects then classed as "nebulæ," the question arose whether, with sufficient power, all "nebulæ" might not be resolved into discrete stars. Fortunately, the invention of the spectroscope about 1860 and Dr.

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[*] Read before the Chicago Academy of Sciences, Feb. 7th, 1893.

[†] See Kant's "*Allgemeine Naturgeschichte und Theorie des Himmels*," published in 1755; *Sammtliche Werke*, vol. 1, p. 207.

[‡] See "*Systeme du Monde*," *Note VII et Derniere*, p. 498.

[§] See Laplace's remarks in the Introduction to his "*Theorie Analytique des Probabilites*," p. LXVII.

[‖] Newton regarded the planets as having been set in their orbits by immediate hand of the Deity, and held that the fixed stars had been intentionally placed at such vast distances apart in order that they might not fall upon one another by their mutual gravitation. See his remarks in the "*Scholium Generale*" at the close of the "*Principia*."

Huggins' application of it to the study of the heavenly bodies at once answered this question in the negative, by showing that many of the nebulæ are masses of glowing gas in the process of condensation; and hence it then became a matter of great scientific interest to investigate the formation of the heavenly bodies.

The principle of the conservation of energy and the mechanical theory of heat, which Helmholtz was the first to apply to the nebular contraction of the Sun,* and Lane's researches on condensing gaseous masses,† together with the researches of Sir Wm. Thomson on the Sun's age‡ and heat, have each marked important epochs in the development and confirmation of the Nebular Hypothesis as now maintained and generally accepted by astronomers. The nebular origin of the heavenly bodies being at present generally conceded, the main question of interest relates to the process involved in the development of cosmical *systems*.

The Nebular Hypothesis of Laplace supposes the planets and satellites to be the condensed products of rings successively shed by the contracting nebula which originally contained the matter of the solar system, and this theory of ring-formation has exercised extraordinary influence over the minds of scientific men. Prior to the researches of Professor G. H. Darwin on the origin of the Lunar-Terrestrial System, the theory of ring-formation appears never to have been seriously questioned, at least as respects the planetary evolution. But Professor Darwin's discovery of the exceptional formation of the Moon, and his introduction of the important physical agency of Tidal Friction (which was entirely overlooked by Laplace) necessitated considerable modification of the original Nebular Hypothesis, and constituted perhaps the most important step in scientific cosmogony made during this century. Since Tidal Friction is a necessary adjunct of gravitation wherever systems of fluid bodies exist in a state of relative motion, we perceive that it is a physical agency as universal as gravitation itself, operating more or less powerfully in all the systems of the universe.

It is but proper to state, however, that Professor Darwin's researches on Tidal Friction were applied only to the solar system, in which the conditions are highly unfavorable to the Theory (except in the case of the Earth and Moon), chiefly on account of the relatively small masses of the attendant bodies. In the stel-

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* See the Popular Lecture delivered on the occasion of the Kant Commemoration at Königsberg, Feb. 7th, 1854.

† See "American Journal of Science," July, 1870.

‡ See "Popular Lectures and Addresses" of Sir Wm. Thomson, vol. I. p. 349.

lar systems, where each body is sufficiently large to have a considerable moment of momentum of axial rotation, the secular effects of Tidal Friction must be of far greater importance, and it will therefore not be surprising if we find that this physical agency has played a more prominent part in the development of such systems than even in the case of the Earth and Moon. It may be remarked that nearly all the cosmogonic speculations hitherto promulgated have been advanced with especial reference to the solar system. For it appears that no systematic investigation of the origin of Double Stars was ever attempted prior to my own researches, which were begun in an elementary manner about four years ago.

The first step in the investigation was the collection of a Table of the best orbits available, which were found to be highly eccentric in comparison with the orbits of the planets and satellites. It was at once evident that so remarkable and fundamental a difference could not be overlooked in explaining the origin of the double stars, and the high eccentricities seemed to point with overwhelming probability to the operation of some powerful physical cause which had not left a corresponding impress upon the orbits of the planetary system. Accordingly, it occurred to me that the cause which had elongated the double-star orbits might be the secular gravitational reaction arising from Tidal Friction in the bodies of the stars—an hypothesis that has been confirmed by subsequent mathematical research, in which methods were followed analogous to those employed by Professor G. H. Darwin in his graphical history of the system of the Earth and Moon. I had seen no intimation that Tidal Friction could increase the eccentricity, but soon proved it for the case in which the tides lag (less than 90°), only to discover afterwards that a similar result had been reached by Professor Darwin several years earlier,* though it had not been given any particular prominence, and was apparently but little known; hence the discovery that Tidal Friction could increase the eccentricity was an independent one, since at that time my knowledge of Professor Darwin's work was based upon a review† which gave no account of the secular changes of the eccentricity arising from Tidal Friction.

In the present discussion of the working of Tidal Friction, we shall first present some of the secular effects in an elementary

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* See Article *Tides*, *Encyclopædia Britannica*, vol. XXIII, p. 378; also Professor Darwin's well-known papers in the *Philosophical Transactions* and *Proceedings* of the Royal Society from 1878 to 1882.

† Miss Clerke's "History of Astronomy during the 19th Century."

geometrical manner, and at length give a rigorous diagram embodying the graphical history of a double-star system.

Self-luminous bodies, such as the Sun and double stars,* are certainly in a fluid state (the term *fluid* being used in the most general sense) and there is reason to believe that the viscosity or "stiffness" of the fluid is usually small. Therefore the tides raised in such masses by the attraction of foreign bodies will not be confined to the surface (as in the case of the fluid oceans surrounding the nearly rigid Earth), but will extend throughout the whole mass; such tides are termed *bodily* tides, and it is with them that we are here concerned. Now imagine a double-star system, whose components we shall call respectively Helios and Sol,† each of which is of the same order of mass, and same general physical condition as the Sun. Suppose both stars to be spheroids endowed with rotations which are rapid compared to their period of revolution about one another, in the same direction, and about axes nearly perpendicular to the plane of orbital motion.

Let the system be started with the spheroids at a considerable distance apart, so that the attraction of either upon the other becomes practically the same as if the masses were collected at the centres of gravity, and suppose the orbit given a small eccentricity. Then, since the fluid is more or less viscous, the tides raised in either mass by the attraction of the other will lag, and if the viscosity is small the angle of the lag will be only a few degrees. For simplicity we shall now treat the spheroid Sol as having its mass collected at its centre of gravity, and examine the effects on the eccentricity arising from the tidal reaction of Helios; but it must be remembered that in general the whole effect of Tidal Friction in the system of stars will depend upon the aggregate effect of the double tidal reaction arising from the rotations of both bodies—a complication that renders the rigorous investigation in general very difficult.

With Sol thus reduced to a weighted point revolving in the plane of the equator and raising tides in Helios, the tidal configuration will be something like that indicated in Figure a.

In the position of the tidal ellipsoid of Helios shown in the figure the whole attraction on Sol does not pass through the center of inertia *C* (about which Helios rotates), but some point *c*. The reaction of Sol is equal and opposite, and hence there arises

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* A part of this discussion is reproduced from *Knowledge* of May 1892.

† These names are chosen to fix the attention upon a system composed of two sun-like bodies, such as we find in double-star systems.

a couple (with arm $c\ C$) acting against the rotation of Helios. We may resolve the whole attraction of Helios ($c'c$) into two components, one of which ($c'C$) passes through the centre of inertia C and produces no effect, as it is counteracted by the centrifugal force of the revolving body. The other component ($c'd'$) perpendicular to the radius vector is unbalanced by any opposite force, and hence acting as an accelerating force tends to increase the instantaneous linear velocity, whereby there results an increase in Sol's mean distance.

As the axial rotation of Helios is reduced, Sol is wound off on a spiral whose coils are approximately in the same plane and very close together. To speak mathematically, the *moment of momentum* of the whole system is *constant*,[*] and since the reduction of Helios' rotation causes the axial moment of momentum to diminish, it follows that the moment of momentum of orbital motion must augment. In other words, Tidal Friction transfers moment of momentum of axial rotation to moment of momentum of orbital motion, and hence the mean distance must increase.

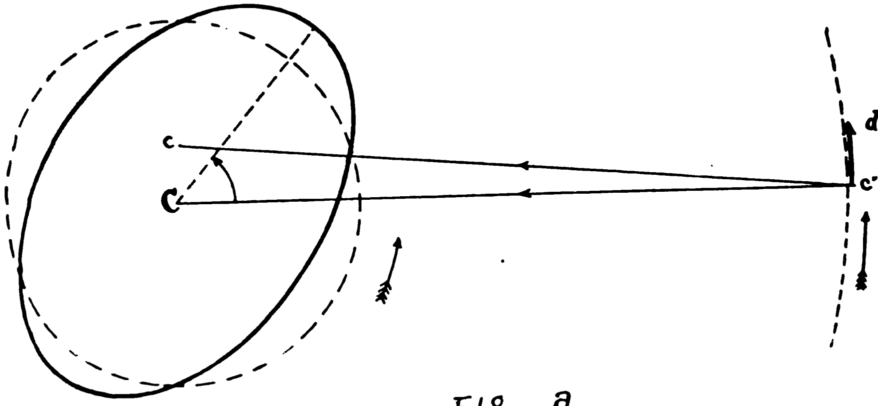

Fig a

With these very brief introductory remarks, let us now examine the changes of the eccentricity of the orbit. In the mathematical works on the Tidal Theory it is shown that the tide-generating force varies inversely as the cube of the distance of the tide-raising body. The height of the tide varies directly as the tide-generating force. The couple acting against the rotation of Helios arises from the excess of the attraction of Sol on the

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[*] The *energy* of the system, however, is not constant, but continually diminishing, owing to loss of radiant energy.

nearer tidal protuberance above that on the further. Now this excess is found to vary inversely as the third power of the distance between the two bodies. But the couple also varies directly as the height of the protuberance (*i. e.* as the height of the tide), and this height varies inversely as the third power of the distance. Hence the Tidal Frictional couple varies as the inverse sixth power of the distance; or it may be described as varying inversely as the square of the tide-generating force, since the tide-generating force varies inversely as the cube of the distance. If we denote the Tidal Fractional couple by T, the radius vector by ρ, the tangential force by t, the principle of action and reaction gives, for the equilibrium of the forces, $T = t\rho$, or $t = \frac{T}{\rho} = \frac{\varkappa}{\rho^7}$, since T varies as $\frac{1}{\rho^6}$.

Therefore the tangential disturbing force varies inversely as the seventh power of the distance of the tide-raising body.

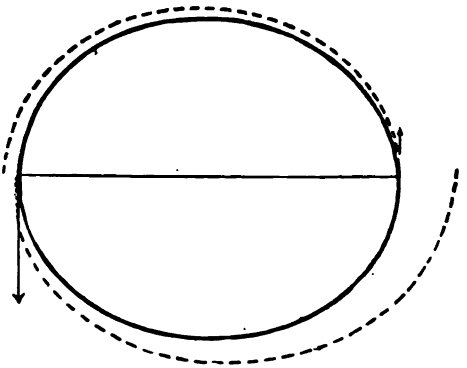

Fig. b.

When Sol is in perihelion the tides are higher (in the inverse ratio of the cube of the distance) and the tangential disturbing force is greater than when Sol is in aphelion, in the inverse ratio of the seventh power of the perihelion and aphelion distances. It is well known in the theories of planetary motion that a disturbing acceleration at perihelion causes the revolving body to swing out further than it would otherwise have done, so that when it comes round to aphelion the distance is increased. In like manner, an accelerating force at aphelion increases the perihelion distance, somewhat as we have roughly shown in Fig. *b.* Now, if we consider the Tidal Frictional component to act instantaneously and only at the apses of the orbit, the effect would be to increase the perihelion as well as the aphelion distance, but the latter at such an abnormally rapid rate that the orbit becomes more eccentric.[*]

If the orbit is not very eccentric similar reasoning to that just employed for the two apses could be applied to other opposite points in the orbit, and the same general results would follow; when, however, the eccentricity is considerable, this method of procedure is not so satisfactory, though while the tides lag, as in Fig. *a*, the eccentricity will continue to increase.

We shall now present the effects of Tidal Friction as the converse of those arising from a resisting medium, and shall determine the law of the density of the medium required to counteract the effects of Tidal Friction. Let us consider the case in which the orbit has only a moderate eccentricity (say not surpassing 0.3), since practically the whole disturbing force due to the tides in Helios may then be regarded as acting in the tangent to the orbit. When the tides lag (less than 90°, as in Fig. *a*), the tangential component is directed forward, and hence tends to accelerate the instantaneous linear velocity; the force arising from a resisting medium is directed continually backward, and hence tends to cause the instantaneous linear velocity to diminish. The two forces are therefore oppositely directed, and hence it is evident that if they acted simultaneously the orbit would not undergo the least change either in size or shape, but would be rigorously stable. Now, the resistance encountered at any given point of the orbit depends upon the density of the medium, and is also proportional to the square of the instantaneous linear velocity; but from Kepler's law of equal areas in equal times, it follows that the momentary velocity of the revolving body varies inversely as the radius vector. The tangential accelerating force due to Tidal Friction varies inversely as the seventh power of the distance; therefore, in order to counterbalance this by a retarding force due to resistance we must suppose the density of the medium to vary inversely as the fifth power[†] of the distance from the centre. Such a medium would give a resistance that would

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[*] If the eccentricity is to remain constant the increase must be in the ratio of $(l-e)$ to $(l+e)$; with Tidal Friction the ratio is more nearly $(l-e)^7$ to $(l+e)^7$, though not rigorously so, except when the eccentricity is very small.

[†] If σ be the density of the medium, ρ the radius vector, and $\varkappa$ some constant, then the tangential resistance t' varies as $\varkappa\sigma v^2$, but v^2 varies as $\frac{1}{\rho^2}$; therefore t' varies as $\frac{\varkappa\sigma}{\rho^2}$. The tangential disturbing force t varies as $\frac{\varkappa}{\rho^7}$, and if t' is to be made equal to t, we must suppose σ varies as $\frac{1}{\rho^5}$. Then $t' = t = \frac{\varkappa}{\rho^7}$.

just annul the changes arising from Tidal Friction. Now, Laplace has shown* that the action of a resisting medium increasing in density toward the centre, according to any law whatever, causes the major axis and the eccentricity of the orbit of a revolving body to diminish. Therefore, Tidal Friction must cause the major axis and the eccentricity of the orbit to increase.†

The stellar orbits are on the average about twelve times as eccentric as those of the planets and satellites. The mean eccentricity of the 70 orbits now roughly known is 0.45, while the corresponding mean for the orbits of the eight great planets and their twenty ‡ satellites is less than 0.0389. The orbit of γ Virginis is known with great precision, and here we have the remarkable eccentricity of 0.9; and the very trustworthy orbit of Sirius, recently computed by Dr. Auwers, has the very considerable eccentricity of 0.63. From a number of other orbits whose eccentricities are very well determined the fact seems certain that the double-star orbits are generally highly eccentric, though some few appear to be more circular, in accordance with the theory of tidal evolution under what are perhaps rather abnormal conditions. Therefore we have in the general elongation of the double-star orbits a visible trace of the action of secular Tidal Friction, which has played so important a part in the evolution of the stellar systems mainly because of the large mass-ratios of the component bodies, and their comparative proximity during immense ages; for it must be remembered that double-stars, now condensed and widely separated, were millions of years ago much closer together and more expanded in volume, and hence the tidal action was then very much greater than at present.

In the *Inaugural-Dissertation*§ recently presented to the Faculty of the University of Berlin, I have discussed, with all possible rigor, the working of Tidal Friction in a system composed of two equal fluid spheroids endowed with congruous rotations about axes nearly perpendicular to the plane of orbital motion

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* *Mecanique Celeste. Liv.* X., *Ch.* VII, *Sec.* 18; or Watson's "Theoretical Astronomy," p. 552.

† We may add that the increase will usually continue until the rotations of both stars are nearly exhausted, after which the eccentricity will be reduced by the libratory motion of the system, and the orbit will at length become circular. The stars, however, would then perhaps be entirely dark, and hence, if in the immensity of space any such dark rigid double-star systems exist, they cannot be observed. Other relations of rotation and revolution, and various other viscosities, give rise to various other results; but the conclusion above reached is that of chief interest in connection with the great multitude of double stars hitherto discovered.

‡ Professor Barnard's new satellite of Jupiter is not here included, but the eccentricity of its orbit also is doubtless very small.

§ *Die Entwickelung der Doppelstern-Systeme,* Dec. 10th, 1892.

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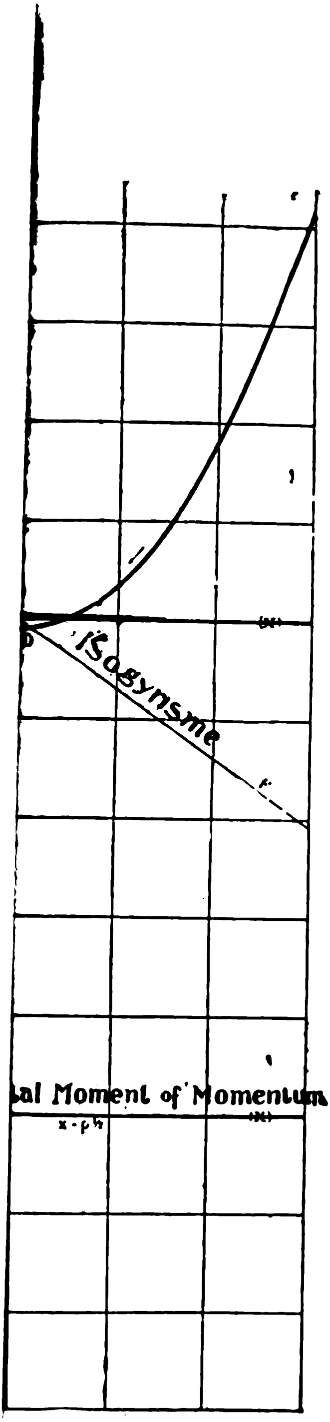

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and in the same direction as the revolution. Without going into the details of the research (which is based on Darwinian principles), it may be added that the problem is completely solved, for the particular case just mentioned, when the initial velocities of rotation are equal; and in an investigation not yet published I have been able to show that the history of the system in all other cases will be essentially similar. Therefore, the results arrived at in this particular case (where the spheroids are identical) and directly applicable to a system of equal stars, such as γ Virginis, will also be applicable generally.

Now, since the system is non-conservative, the energy must degrade (owing to the loss of radiant energy arising from tidal molecular friction), and hence the ordinates of a curve representing the total energy of the system must decrease with the time. The rigorous dynamical equations are illustrated in Diagram E, which gives the graphical history of the system. The energy curve is given by the equation

$$E = \frac{(H-x)^2}{2} - \frac{1}{x^2},$$

and the curve of Rigidity (Starrheit) by

$$x^3\eta = \sqrt{2},$$

while the Isogyrisme (a line which corresponds to Darwin's "line of momentum," where only one body rotates) takes the form

$$\eta = \frac{H-x}{\sqrt{2}}.$$

In these equations, x represents the moment of momentum of orbital motion and is also proportional to the square root of the mean distance between the two bodies; H represents the whole moment of momentum of the system, which is constant; E, the whole energy (both kinetic and potential) of the system, which must diminish under the action of Tidal Friction.

The three equations just given are illustrated by curves (in the upper part of the diagram), which are referred to the origin 0′. In the lower part of the diagram we have the eccentricity curve, which (to avoid confusion of too many curves) has been referred to the origin 0. The equation for the eccentricity curve is very complicated, and need not be given here.

Now, every point on the energy curve represents one configuration of the system (*i. e.* one mean distance, or one orbital angular velocity, and one axial velocity of rotation) and there are corresponding points (which have the same abscissas) on the eccentricity curve, the Isogyrisme, and the rigidity curve. (We may remark, however, that the *eccentricity curve* does not give the *absolute*, but only the *relative* fluctuations of the eccentricity.) By the nature of the system, the point on the energy curve, when supposed to represent a configuration of the system, must slide down a slope of the curve, as indicated by the arrows, and resulting changes in the eccentricity are to be interpreted as shown in the figure.

When the bodies are first separated the configuration of the system (which moves nearly as though rigidly connected) is that indicated by the point *a*; the *guiding point* of the system (as we call the point representing the configuration) may here slide down the curve *ac* (in which case the bodies fall together, since *x*—the square root of the mean distance—continually decreases) or it may slide down the slope *ab* (in which case the bodies separate from each other—as actually takes place with systems existing in space). Where the bodies separate, the distance will continue to increase until the rotations of the bodies are exhausted and the system reaches a configuration of minimum energy. We observe that as the bodies recede from each other the eccentricity at first slightly decreases (owing to a sort of libratory motion in the system), and, after passing the minimum value, increases until a high maximum is attained, when the bodies revolve at a great distance from each other and with a long periodic time. Without going further into detail, it may be remarked that the career of the system included in the slope *ab* and the corresponding part of the eccentricity curve appears to be that which is usually fulfilled in nature.

We see therefore that as the mean distance of the bodies increases, the eccentricity also increases and attains a maximum, after which it falls (when the bodies lose their relative motion and begin to move as though rigidly connected—a state which would supervene when the bodies cease to contract).

The eccentricities of the double-star orbits appear therefore to have been *developed* in the course of vast ages, and will in the lapse of thousands of centuries also disappear; but by that time the (dark) systems will have become rigid, so that systems in this state (of minimum energy), if any exist, are necessarily invisible. The orbits of *observed* double stars are therefore highly eccentric, and in this elongation of the orbits we have a visible trace of the working of a physical cause, which, for millions of years, has been changing the size and shape of the orbits.

In order to ascertain whether the action of Tidal Friction could satisfactorily explain the expansion and elongation of the douits, I took an *ideal system* (in default of accurate of any *real system*) and derived numerical results ır abundantly to confirm the theory.

ımerical calculation, it was supposed that the two ere identical homogeneous nebulous masses, each as massive as the Sun, expanded to fill the orbit of endowed with an axial rotation such as to give an f 0.4. These spheroids were supposed to be placed distance equal to that of Neptune from the Sun, and g in an orbit with an eccentricity of 0.1. Then, it hat as the semi-major axis increased under the action tion, the eccentricity also increased, and attained a f 0.57 when the mean distance was 49.388 astrots, after which the eccentricity again decreased (owibratory motion in the system) and vanished when m of energy was reached at a mean distance of es the distance of the Earth from the Sun. In other l Friction had nearly doubled the semi-major axis of hile it had also rendered the eccentricity larger than centricity observed among the double-stars. From ation it also appeared that the maximum eccentricity a system depended largely upon the initial eccenwhich the system was started, larger initial ecceng larger maxima for this element.

therefore that the Theory of Tidal Friction abunins the larger as well as the smaller eccentricities, remains to discuss the process by which a nebula ating axial rotation splits up into two comparable

ıré* and Professor Darwin† have investigated the of rotating masses of fluid with a view of testing eory of the formation of the planets and satellites. es are widely different in character, but they lead to the same result, namely: That when equilibrium in a rotating mass the portion detached by increasvelocity, should bear a far larger ratio to the parent s observed in the planets and satellites of the solar , moreover, that while the separation might ideally the form of a ring, the general process of division ise to masses of a more or less globular form. The I. Poincaré is given in the accompanying figure

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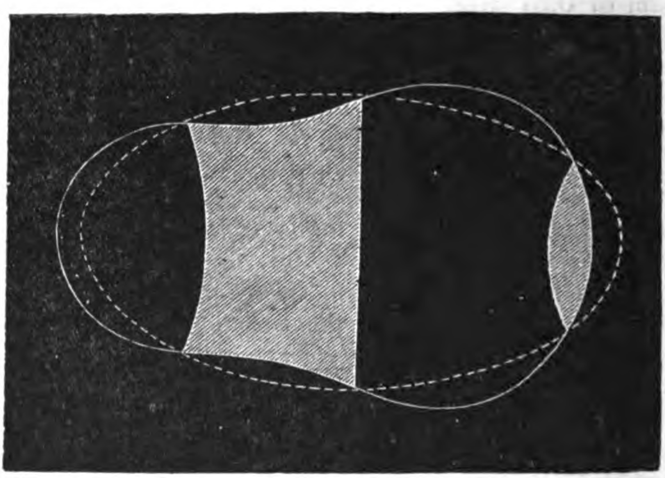
bematica, vol. VII.

s., 1887.

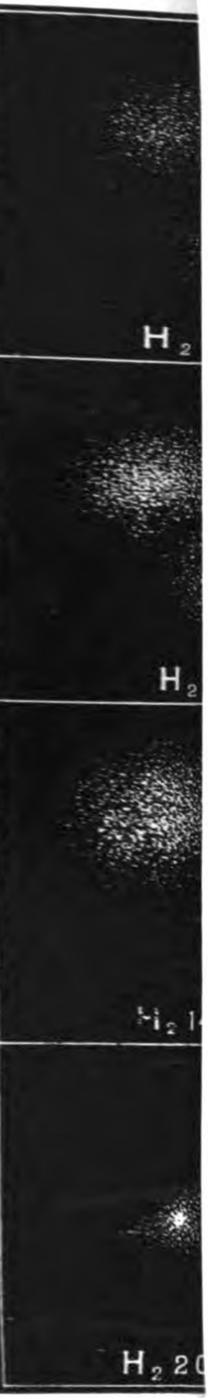
which shows the manner in which the Jacobian ellipsoid unde increasing axial rotation becomes unstable and finally breakes u into two comparable masses, by a sort of division resemblin "fission" among the Protozoans. That this process of separation actually occurs in space will be evident on comparing th Apioid with Sir John Herschel's drawings of double nebula which are here reproduced. It seems legitimate to conclude tha the double nebulæ have originated from single (perhaps irregular masses by the process of "fission" arising from increasing rotation, and that in the course of millions of years they will develo into double stars.



M. POINCARÉ'S APIOID.

Double nebulæ have been greatly neglected since the time of Si John Herschel, but it is to be hoped that astronomers will agai give adequate attention to these remarkable objects, whic should be at once systematically studied and photographed. I accurate drawings or photographs of these objects were no made, it is not to be doubted that important changes could b observed 50 years hence.

Should the theory of double-star evolution here briefly and imperfectly sketched prove to be substantially true, I think it wi be conceded that it throws considerable new light upon the problem of the formation of the heavenly bodies. For hithert nearly all investigators have proceeded in their researches fro the point of view of the solar system, notwithstanding the fac that our system is very remarkable, and indeed different in tw respects from any other hitherto discovered:



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The revolving bodies are very small relative to the central
(except the Moon whose mass amounts to $\frac{1}{80}$ of the
mass).
The orbits are nearly circular (we neglect the asteroids
nets).
louble-star systems are remarkable for:
The large mass-ratios of the component bodies.
The high eccentricities of the orbits.
ms hardly credible, and yet it is a fact, that the Sun has
nes the mass of all the attendant bodies combined; hence
that practically all the mass of the solar nebula has gone
e Sun. In double-star systems, the masses, if not equal,
least *comparable*. In other words, *the mass-distribution
solar system is essentially single, whereas in double-star
s it is essentially double.*
efore it is not wonderful that Tidal Friction has played so
ient a part in double-star systems, and has been so unim-
t in the solar system, where the masses of the revolving
are so small as to render their moments of momentum of
otation inefficient in changing the size and shape of the
Considering the exceptional character of our system, are
therefore justified in affirming that the general law of cos-
levelopment can only be deduced from the study of other
is in space, and especially of double-stars and double nebu-
ich seem to typify the normal form of celestial evolution?
the importance of studying double stars and double nebulæ
the more easily perceived, as will also the interest attach-
multiple stars and clusters, which deserve the most careful
and the most systematic investigation. For if all the
rs now visible in the heavens were carefully studied and
red, by means of Photography, it is not to be doubted that
a century some progress could be made towards explaining
rmation of these wonderful aggregations of stars, concern-
hich we are at present profoundly ignorant.
dequate attention is given to other systems in space, we
e sure not only that true cosmonony will be greatly ad-
d, but that we shall also gain additional light respecting
rmation of our own extraordinary system, whose develop-
seems to have been somewhat anomalous.
even in the case of the solar system, it is questionable
ier the theory of ring-formation is applicable, except in the
f Saturn's rings and the asteroids—two formations which
nnected by striking analogies and appear to be exceptions

in the planetary evolution. Laplace's theory of ring-formation although mathematically sound in principle, fails utterly whe applied to the actual systems of the Universe at large, as we infe from the well-known rarity of ring nebulæ and the great abundance of double nebulæ and double stars. It is to be remarked however, that it was not known in the time of Laplace that rotating mass of fluid could assume any other than symmetrica figures of equilibrium (including, of course, the *annular form*) but from the researches of Poincaré and Darwin we infer that un symmetrical figures such as we observe in double nebulæ are no only ideally possible, but are in general actually realized in nature. Therefore, since the planets also could have separated i the form of globular masses, there is no longer any logical reason for holding the theory of ring-formation, except in the case o Saturn's rings and the asteroids, which appear to have been exceptional.

There are other nebulæ worthy of study, particularly the spira nebulæ, but since their true figures remain unknown, they hav not been considered in this discussion. If adequate attention i given to double, multiple, and spiral nebulæ, future research wil throw light upon problems which now remain obscure, and in the course of time we shall perhaps be able to reach a definit conclusion respecting the formation not only of our own system but of systems generally. And when sufficient data have been collected to throw light upon the results of theory, cosmogony ought to rise from the plane of mere speculation to the rank of real science. If we shall at present succeed in discovering the law of double-star evolution, no inconsiderable advance will have been made in the right direction.

THE UNIVERSITY OF CHICAGO,
1893, Feb. 7th.

ON THE RELATIONS WHICH OBTAIN BETWEEN THE MEAN MOTIONS OF JUPITER, SATURN, AND CERTAIN MINOR PLANETS.[*]

DANIEL KIRKWOOD.

The interesting relations between the mean motions of Jupiter's first three satellites are known to every astronomer. From the date of the first exact observations, these bodies have moved

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[*] Communicated by the author.

harmony with this remarkable law. But who, with-
nstration, would have ventured to affirm it rigidly ex-
lace proved that if the original motions had *very*
ese relations, the mutual influence of the satellites
time, have rendered them perfectly true. Back of this
ever, remains the unsolved question—Why were the
nasses, positions, and motions of the three bodies in
such that nothing more was necessary than a slight
fluence to render the phenomena forever permanent?

disturbing effect of Jupiter and Saturn, especially of
, in the asteroid zone, may obviously have been some-
lar. Putting

$n^{V}=$ the mean daily motion of Jupiter,
$n^{VI}=$ that of Saturn,
$n^{(279)}=$ that of Thule,
etc., etc.,

er special relations at the orbits of commensurability.

$$3n^{(279)}=4n^{V} \qquad (1)$$

$$n^{V}=299''.1284$$

$$n^{(279)}=398''.8376 \qquad (2)$$

$$-3n^{(279)}+2n^{V}=0 \qquad (3)$$

$$n^{(318)}=597''.919 \qquad (4)^{*}$$

$$2n^{(153)}=3n^{V} \qquad (5)$$

$$n^{(153)}=448''.6926 \qquad (6)$$

$$2n^{(188)}=5n^{V} \qquad (7)$$

$$n^{(188)}=747''.8210 \qquad (8)$$

$$n^{(279)}+2n^{(153)}=0 \qquad (9)$$

$$^{VI}-3n^{V}+n^{a}=0 \qquad (10)$$

$$n^{a}=656''.4\pm$$

tical region indicated in (10) is about the orbits of
8 and Chryseis 202.

ts of the system indicated by equations (1) to (10),
interesting phenomena, suggest fruitful themes for in_
is doubtless impossible to calculate the infinitesimal
ons of asteroids, but the disturbance of their motions
planets is a legitimate object of investigation.

E, California.

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ch's value—Anniuare 1893.

SOME EFFECTS OF A COLLISION BETWEEN TWO ASTEROIDS.*

SEVERINUS J. CORRIGAN.

The motion of particles projected horizontally from the central body or asteroid under discussion, will now be considered. The paths through which they move must, of course, be arcs of some one or other of the conic sections, the form of curve depending upon the velocity of projection.

A velocity which is given by the equation

$$V = k \cdot \sqrt{\frac{2m'}{R}} \tag{7}$$

in which, R, represents the radius of the central body whose diameter is 74 miles, and the other quantities have the signification assigned them on preceeding pages, would throw a particle off in a parabolic curve, while under any greater velocity this particle would describe the arc of a hyperbola, and in either case it would never return to the central body. On the other hand, a less velocity would cause such a particle to move in an elliptical, possibly in a circular orbit, and if the orbit be an ellipse of sufficiently great eccentricity, this particle might move out in practically a straight line, and then fall back toward the center of gravity of the central mass, or asteroid.

With the value of the mass, m', and of the radius, R, of the asteroid aforesaid, it is found, through equation (7) that the initial velocity at and above which a particle endowed therewith, could never return, is 341.2 feet per second.

Let us now suppose that the small dark disc in Fig. 1, represents the central body or nucleus, aforesaid, and that this body is subjected to an impact from another like body moving from right to left.

Then particles projected by this impact, horizontally, from the points, A and B, with the above specified velocity of 341.2 feet per second, will describe parabolic arcs, AC and BC, which may be regarded as limiting lines within which particles cast off by the same force due to the impact, but with a less, or an elliptic, velocity, must be found. The lines AD and BD may, in like manner, be regarded as arcs of a hyperbola, which arcs particles projected with some indefinite velocity greater than parabolic must describe and as limits within which matter whose initial velocity

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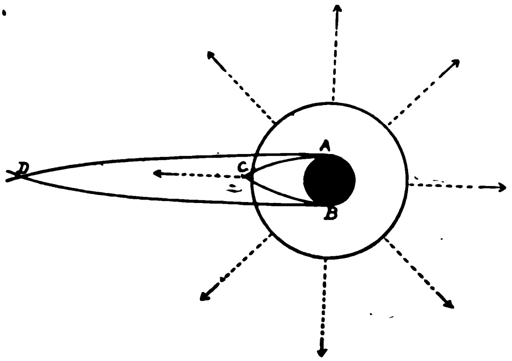
* Communicated by the author. Continued from page 212.

veen the parabolic and the indefinite hyperbolic velocity
d, must move.

amination of Fig. 1, which has been constructed from
heoretical deductions from the principles above set forth,
hink, disclose a remarkable resemblance between that
d the actual appearance of Holmes' comet as admirably
by Dr. H. C. Wilson in No. 111 of ASTRONOMY AND AS-
SICS.

ot mean that the above depicted diagram is a *fac-simile*
that it corresponds with his in the relation and signifi-
the several parts. Thus, the small black disc represents
ral body, asteroid, or nucleus, the dotted arrows, the
rojected radially at high (*i. e.* parabolic or hyperbolic)

FIG. 1



and dispersing in space under the action of the Sun;
represents the condensation around the nucleus, its ra-
g that of the "sphere of control," which radius has been
ed by ρ; the short tail depicted by Dr. Wilson has its
art in the matter included between the lines AC and BC,
ong one, by that lying within the lines AD and BD. The
pearance of the comet thus indicates that that body is
lt of a *collision* rather than of an *explosion*, the im-
ving been caused by a more rapidly moving body ap-
g from the direction opposite to that indicated by the
resaid. Between Nov. 6, 1892, and Dec. 23 following,
ter "tail" grew to a length of nearly 2°, which would in-
average velocity for the particles constituting that ap-
amounting to about 7,500 feet per second, a hyperbolic
nearly 22 times as great as the parabolic velocity at the

narkable phenomena exhibited by this comet (or quasicomet), on Jan. 16, 1893, and which were witnessed by Dr. Wilson and other astronomers whose descriptions thereof appeared in No. 112 of ASTRONOMY AND ASTRO-PHYSICS, furnish strong evidence in favor of the "collision" hypothesis. In the "Comet Notes" of the aforesaid number, I suggested that this renewed activity and re-illumination was due to the fall and condensation of matter which had been projected from the nucleus on, or a little before, the date of Holmes' discovery. Matter so projected radially, and falling back toward the centre of gravity of the cometary mass, may be regarded as having moved in an elliptic orbit of such great eccentricity that it was practically, a straight line. Now, since whatever may be the eccentricity of the elliptic orbit, Kepler's third law governs the motions of matter revolving therein, the mean distance *a* of such an orbit can be found through the equation

$$a = \sqrt[3]{m'k^2T^2} \tag{8}$$

in which T represents the time of revolution, *i. e.*, the time occupied by a particle in going out to the extreme limit of its path or to the outer apsis of the elliptic orbit, and returning to the centre of gravity of the cometary mass.

If the matter left the central body on the occasion of the first appearance of the comet, or shortly before the date of discovery, on Nov. 5th, 1892, for instance, and returned on Jan. 16th, 1893, the value of T would be 72 days. With this value and those of the other quantities in the second member of equation (8), which are known, the mean distance *a* is found to be 4,289 miles, and twice this, or 8,578 miles, is the distance to which this matter must have been projected by the impulse due to the collision.

The limit of the "sphere of control," or ρ is, as has been determined above, about 25,000 miles, so that the mass of *debris* under consideration was hurled to only a little more than ⅓ of that height; this is what would naturally occur, because it is probable that, judging by the effects observed on Jan. 16th, this mass was composed of the larger ejected particles, whose initial velocity was less than that of the smaller particles, or finely divided matter, comparable to dust, which therefore rose to greater heights up to the limit of 25,000 miles. Now let us note the probable movements of such a mass of matter so projected and the effects produced thereby. After rising to the height of 8,578 miles in 36 days, it would begin its descent. Scattered in space at that height, it would not be at all conspicuous, unless it were in very great quantity, but as it neared the centre of gravity, or

as, about Jan. 16th, 1893, the concentration of this mat-
omparatively limited space would increase the brilliancy
parent nucleus by an amount directly dependent upon
ce which this condensed matter would present. If we
the particles to have been in such numbers, or of such
when near the nucleus, they presented a solid surface,
bout 400 miles in diameter, or equal in this dimension
the application of equation (6) would give the magni-
e apparent nucleus, supposing its luminosity to be due
ed light only. The last term of the second member of
ation would, under these conditions, become zero, and
ting magnitude for Jan. 16th would have been 7.5.
hough it is not known whether the falling matter under
tion was sufficient in quantity to produce the apparent
miles in diameter, or otherwise, it is interesting to note
he above named date, Dr. Wilson of "Goodsell Observa-
scribed ("Comet Notes," A. and A.-P., No. 112) the nu-
at first hazy, afterwards more star like, and about as
an 8 mag. star." Professor Barnard of "Lick Observa-
imated it, at the same time, as of the 7.5 or 8 magni-

thus falling would, for a long time, move very slowly,
neared the nucleus, the action must have been greatly
ed, causing the apparent nucleus to seemingly enlarge,
ighten greatly in a remarkably short time, while the il-
on of the surrounding finely divided matter, or dust
use the comet to apparently increase in size in a remark-
d and unaccountable manner. Shortly afterward, or so
ll the falling matter reached its original position on the
the brightness of the latter would fall to the normal
le due to the surface presented by the central body whose
ns were given on a preceding page.
ashing of the falling particles as their motions were
must have resulted in the projection of finely divided
or dust, and therefore, in the repetition, on a smaller
the phenomenon of "expansion" of the comet, which
otable a feature of that body shortly after its discovery.
ll of these probable effects were actually observed by Dr.
Professor Barnard and other astronomers, on Jan. 16,
d I believe, therefore, that these observers caught sight
ling matter very nearly at the time that it reached the
entral body or asteroid.
sidering the heating effects produced by such falling

matter, I obtained a rather surprising result: As is well known, if the velocity of a moving mass be arrested, and no mechanical effects be produced thereby, the kinetic energy of such mass will be converted into heat, and t, or the number of degrees Fahr., by which any mass of weight, w, would be heated up by reason of such arrested motion, is given by the equation,

$$t = \frac{2wv^2}{100{,}000s} \tag{9}$$

in which v is the velocity, in feet per second, and s the "specific heat" of the substance. If we take the "specific heat" of the matter under consideration as equal to that of the metals of the iron group, or about 0.1, we will probably be very near the truth, in any case sufficiently near for the present purpose. The maximum initial velocity of projection of matter ejected from and returning to the nucleus was found through equation (7) to be about 341 feet per second, and this may be taken as the maximum velocity with which the falling matter could strike the surface of the central body. With this as the value of v, in equation (9), and taking w as one pound, I find that the temperature by which that pound of matter would be raised by such a fall, would be only 23° Fahr. Now, since small masses of matter out in space and devoid of atmospheric envelopes, have probably nearly the temperature of the surrounding "ether" (which temperature is now considered to be not far above absolute zero, or — 459° Fahr.) it follows that, since to raise such matter to even a red heat, the augmentation of temperature must be about 1459° Fahr., the small increase aforesaid generated by the fall, is practically *nil*, and the illumination of the cometary matter could not have been due to high temperature. If the heat generated could have been concentrated in a very small portion of each pound of matter, a sufficiently small portion might have been raised to the temperature of incandescence, but by conduction and radiation even that portion of the matter would have cooled almost instantaneously. Therefore in so far as this source is concerned, the conclusion arrived at, and which seem to have been confirmed by the spectroscope, is that the light of the comet was reflected light, and that the great increase therein observed on January 16th, 1893, was due simply to the greater surface presented by the concentration of the falling matter around the nucleus, from which matter the light was reflected.

The heating effects due to the original collision could also be

re knew the velocity of each of the colliding bodies at the
of the catastrophe, on November 5, 1892, for instance.
e the velocities of these bodies are unknown, the proba-
mum effect may be determined by finding the greatest
east velocity possible at any point, for known asteroids
common radius-vector, which they must have if in col-
d supposing that the orbits are such that these bodies
ide.

ear velocity of any member of the "solar system," when
stance, r, from the Sun, is given by the equation

$$V = k.\sqrt{\frac{2}{r} - \frac{1}{a}} \qquad (10)$$

given value of r it depends therefore only on the value
he mean distance of the planetary body. Now among
oids examined "Thule" (279) has the greatest mean
nearly 4.26253, and "Sita" (244) the least, which is
17460, while r, or the radius-vector of the "comet" or
mbined bodies in collision was, on November 5, 1892,
38885. With these values in equation (10), the velocity
e" is found to be, for a radius-vector equal to that above
out 75,000 feet per second, and that of "Sita" nearly
et, and the difference is the greatest relative linear veloc-
ble, at the given distance, r, so far as the same can be de-
from the *known* asteroids having the greatest difference
listance. The bodies aforesaid could not come into col-
that distance, but are simply used to show the maximum
n of relative velocity among the members of the system
they belong. This maximum relative velocity of about
et is, most probably, much greater than the actual rela-
ity of the colliding bodies. On a preceding page it has
ted that the particles forming the longer "tail" of
comet must have moved with a mean velocity of about
t per second. Now since, acccording to the "collision
is, this tail was composed of particles originally belong-
e more rapidly moving body, and of some cast off, by the
rom one moving more slowly, it is interesting to note
relative velocity of such particles lies well within the
n limit aforesaid, being just one-half thereof. I do not
o say, at present, how much value should be attached to
but I think that it may eventually throw some light on
ct, and add something to the strength of the "collision"
is.

We can obtain an approximate knowledge of the effects of impact in altering the respective linear velocities of the two bodies, and, therefore, also the heating effects resulting from such impact through a consideration of the following equations of analytical mechanics. The linear velocities, v_1 and v_2, of two spherical bodies of mass m_1 and m_2, after impact, can be found through the following group of equations numbered (11)

$$\left.\begin{aligned} v_1 &= \sqrt{\left[(1+c)\,.\,\frac{m_1 V_1 \cos\varphi_1 + m_2 V_2 \cos\varphi_2}{m_1 + m_2} - c V_1 \cos\varphi_1\right]^2 + V_1^2 \sin^2\varphi_1} \\ v_2 &= \sqrt{\left[(1+c)\,.\,\frac{m_1 V_1 \cos\varphi_1 + m_2 V_2 \cos\varphi_2}{m_1 + m_2} - c V_2 \cos\varphi_2\right]^2 + V_2^2 \sin^2\varphi_2} \end{aligned}\right\}$$

V_1 and V_2 being the original linear velocities, and φ_1 and φ_2 the angles which the directions of the respective motions make with the normal at the point of impact. In these equations c represents the coefficient of elasticity, being 1 for a *perfectly* elastic body, were there any such, and *o* for a non-elastic one did such a body exist. In the case of perfect elasticity there would be simply a transference of velocities and, therefore, no transmutation of kenetic energy into heat. But by assuming the bodies to be non-elastic, or that c is equal to zero we can obtain the maximum effect, which is the object of this discussion. Moreover since the observations indicate that the bodies were ruptured by the collision, this assumption of non-elasticity will give results nearer the truth than would any other. Furthermore, the masses of colliding bodies may be regarded as equal and by assigning to m_1 and m_2, each, the value of one pound, the final results will be the same as if the actual weight of each body were used. Under these conditions the equations (11) reduce to the following:

$$\left.\begin{aligned} v_1 &= \sqrt{\left(\frac{V_1 \cos\varphi_1 + V_2 \cos\varphi_2}{2}\right)^2 + V_1^2 \sin^2\varphi_1} \\ v_2 &= \sqrt{\left(\frac{V_1 \cos\varphi_1 + V_2 \cos\varphi_2}{2}\right)^2 + V_2^2 \sin^2\varphi_2} \end{aligned}\right\} \qquad (12)$$

If, now, we assume that the impact is "direct and central," as in Fig. 2, the angles φ_1 and φ_2 become each, zero, and we have simply:

$$\left.\begin{aligned} v_1 &= \frac{V_1 + V_2}{2} \\ v_2 &= \frac{V_1 + V_2}{2} \end{aligned}\right\} \qquad (13)$$

As has been found above, the minimum and maximum values of

are 60,000 feet and 75,000 feet per second, respectively,
ve linear velocity being thus 15,000 feet per second, if
ct be "direct and central." This. is, of course, much
robably, than would exist. In fact, if we regard the
f the larger "tail," above refered to, as indicating the
elocity, the latter would be only about 7,500 feet per
Therefore, if we take V_1 as 64,000 feet per second and
00 feet, the results will be much nearer the truth. Us-
in equation (13) for the case of a "direct and central"
in Fig. 2, the values of v_1 and v_2 are found to be equal,
67,500 feet per second. If the impact were *oblique*, as
Fig. 3 (and this is more likely to be the case), the ve-
ter collision must be found through equations (12), and
take the angle φ_1 as zero, as before, while the orbits

FIG. 2

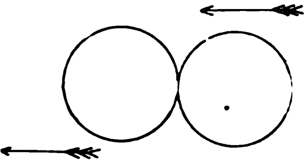
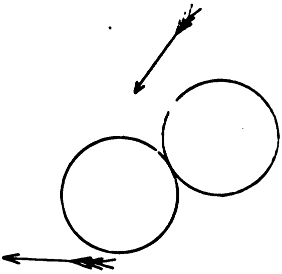


FIG. 3



own asteroids are such that the angle φ_2 cannot be
ater than 20°. The value of v_1 is then found to be
et per second, and that of v_2, 69,724 feet in the same
e *kinetic energy* of a mass **m**, moving with a linear ve-
eing, "½ mv^2," we can find the amount thereof for the
of the moving bodies prior to the collision, and then
their respective velocities after the impact, and if the
less than the former, the difference will be the quantity
energy, either converted into heat, or used in the work
ing the bodies and impelling the resulting particles in
ctions. The application of the above equations gives,
case, a loss of *kinetic energy* amounting to 12,250,000
ds and the effect of this in raising the temperature by
t *t* (if there be no other effects) will be given by,

$$t = \frac{mv^2}{50{,}000s} \qquad (14)$$

e "specific heat" whose value has been given on a preceding page. The value of the rise of temperature for "direct and central" impact as shown in Fig. 2 is found to be nearly 4900° Fahr. But if the impact be *oblique*, as depicted in Fig. 3, the loss of kinetic energy will be much less, being only about 1,860,000 foot-pounds, which would cause a rise of temperature of only 744° Fahr.

Now these two cases are extremes between which the actual case probably lies, and therefore the mean of the values above given, or 2822° Fahr., is the most probable under the supposition that there is no conversion of the kinetic energy into other than *thermic* effects. But since a portion (probably very large) of this energy must have been used in the work of rupture of the bodies, and the dispersion of their resulting particles, even this last named amount is most probably too great.

Moreover, the impact was more likely to be *eccentric* than it was to be *central*, a fact which would still farther reduce the augmentation of temperature. Now since the condition of self-illuminosity requires in this case, an increase of temperature of at least 1500° Fahr., while nearly 2600° Fahr. would be required to raise the matter to "white" heat, the conclusion to which we are led is that while it is barely possible that the body discovered by Holmes could have shone by its own light near the time of its first appearance, rapid radiation of heat must have caused it to soon lose its self-luminosity, and it is more likely that it shone only by reflected sunlight.

In the above discussion two bodies of one pound each have been considered, but if we wish to regard the weight of the whole amount of matter, so far as the same has been determined from the mass as found by the process given in the first part of this article, we can do so by considering the fact that the weight of the Earth is very approximately 13½ septillions of pounds and, therefore, since the mass of the nucleus according to the determination aforesaid, was $\frac{1}{1238970}$ that of the Earth, the weight thereof must have been 10,896,100,000,000,000 pounds, one-half of which would be the weight of each of the equal hypothetical bodies in collision.

In closing this article I would say that, as the title thereof indicates, this subject has been viewed from a *purely theoretical* standpoint and that, whether Holmes' comet is the result of a collision between two asteroids or not, such a collision would produce the results which I have above set forth.

But while I do not wish to attach any undue weight to the several agreements between theory and observation which a

his subject has disclosed, I think that it is highly im-
even well nigh impossible, that these agreements could
rely to a fortuitous concatenation of circumstances.
known, the fact of the agreement or disagreement, be-
ory and observation is the principal "criterion" by
otheses are to be accepted, or rejected, even the great
"universal gravitation" having to stand, as it does
on this foundation.

therefore, that since, in so far as I have been able to
observed phenomena of Holmes' discovery are all ex-
y the "collision" hypothesis, this hypothesis has a
firm foundation upon which to stand. It may be here
that the principles upon which the above discussion is
nded, are the same as those upon which the famous
f "the three bodies" is based, the bodies in this case be-
nucleus" of the comet, the Sun, and any one of the
projected from the nucleus aforesaid. The principal
the discussion set forth in this article have therefore
ed by means of the application of one of the most
d beautiful principles founded upon the great "Law of
Gravitation."

., Minnesota, February 1893.

DIMENSIONS OF SMALL PLANETS.*

D. P. TODD.

not regarded as a matter of astronomical significance,
ions of small planets have an element of interest. The
ters of Clinton calculated the size and superficial area
ll those bodies discovered by himself; and while they
printed in all the recent catalogues of Hamilton Col-
e not seen them elsewhere. They are worth a fuller as-
l circulation; and for completeness I have added to Dr.
ta in the following table the values of g and m_0 for
s from the *Berlier Astronomisches Jahrbuch* für 1894,
aving the following relations to M,

$$g = m_0 - 5 \log a(a - 1)$$
$$M = g + 5(\log \Delta + \log r),$$

mbols having their usual significations.

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nicated by the author.

Dimensions of the 48 Small Planets Discovered by Peters at the Litchfield Observatory of Hamilton College, Clinton, New York.

No.	Name.	m_0	g	Diameter in Miles.	Surface in Sq. Miles.	Date of Discovery.
72	Feronia	11.2	8.9	24.9	1950	29 May 1861
75	Eurydice	11.6	8.4	31.4	3090	22 Sept. 1862
77	Frigga	11 1	7.9	39.5	4898	12 Nov. 1862
85	Io	10.9	7.7	43 3	5888	19 Sept. 1865
88	Thisbe	10.8	7.4	49.7	7762	15 June 1866
92	Undina	10.9	6.7	68.6	14790	7 July 1867
98	Ianthe	11.6	8.3	32.8	3388	18 April 1868
102	Miriam	12.6	9.4	19.8	1230	22 Aug. 1868
109	Felicitas	12 0	8.7	27.3	2344	9 Oct. 1869
111	Ate	11.3	8.2	34.4	3715	15 Aug. 1870
112	Iphigenia	11.5	8.8	26.1	2138	19 Sept. 1870
114	Cassandra	11.1	7.8	41.3	5370	23 July 1871
116	Sirona	10.7	7.3	52.0	8511	8 Sept. 1871
122	Gerda	11.5	7.2	54 5	9332	31 July 1872
123	Brunhilda	11.8	8.5	30.0	2818	31 July 1872
124	Alceste	10.3	7.1	57.1	10233	23 Aug. 1872
129	Antigone	10 3	6.6	71.8	16218	6 Feb. 1873
130	Electra	10.6	6.5	75 2	17783	17 Feb. 1873
131	Vala	12.2	9.5	22.7	1622	25 May 1873
135	Hertha	10.5	7.8	41.3	5370	18 Feb. 1874
144	Vibilia	10 7	7.5	47.5	7080	3 June 1875
145	Adeona	11.3	8.1	39.5	4898	3 June 1875
160	Una	11.8	8.4	31.4	3090	20 Feb. 1876
165	Loreley	11.1	7.0	59.6	11220	9 Aug. 1876
166	Rhodope	12.5	9.2	21.7	1479	15 Aug. 1876
167	Urda	13.0	9.4	22.7	1622	28 Aug. 1876
176	Idunna	12.1	7.9	37.7	4467	14 Oct. 1877
185	Eunice	10.4	7.0	59.6	11220	1 Mar. 1878
188	Menippe	13.0	9.4	19.8	1230	18 June 1878
189	Phthia	11.5	8.8	28.6	2570	9 Sept. 1878
190	Ismene	12.0	6.7	68.6	14790	22 Sept. 1878
191	Kolga	12.0	8.3	37.7	4467	30 Sept. 1878
194	Procne	10.5	7.4	47.5	7080	21 Mar. 1879
196	Philomela	10 3	6 3	82.5	21380	14 May 1879
199	Byblis	12.4	8.2	39.5	4898	9 July 1879
200	Dynamene	11.0	7.6	45.3	6456	27 July 1879
202	Chryseis	10.7	6.7	68.6	14791	11 Sept. 187
203	Pompeia	11.7	8 3	31.4	3090	25 Sept. 187
206	Hersilia	12.0	8.6	——	——	13 Oct. 187
209	Dido	11.6	7.5	54.5	9332	22 Oct. 187
213	Lilæa	11.7	8 3	32.8	3388	16 Feb. 188
234	Barbara	11.7	9.1	——	——	12 Aug. 188
249	Ilse	13 6	11.1	——	——	17 Aug. 188
259	Aletheia	12.1	8.0	——	——	28 June 188
261	Prymno	11.9	9.4	——	——	31 Oct. 188
264	Libussa	12.1	8.6	——	——	17 Dec. 188
270	Anahita	11.0	8.9	——	——	8 Oct. 188
287	Nephthys	10.7	8.2	——	——	25 Aug. 188

The diameters of (1) to (71) are given by Stone in M. N. R. A. S. XXVI (1867) p. 302, and in Houzeau's *Vade Mecum de l'Astronomie*, p. 638.

GLECTED FIELD OF FUNDAMENTAL ASTRONOMY.*

J. R. EASTMAN.

ble threads it is possible to observe the zenith distances
s with a fair degree of precision, because the operation
nparative deliberation and the center of the mass of
placed midway between the threads with little diffi-
the attempt to note with a chronograph key, the in-
a swiftly moving and irregular mass of light, like *α*
ris or *α* Lyræ, is bisected by a transit thread, is an
hat rises but little above the level of ordinary guess-
nsits of first and second magnitude stars cannot be
ith an objective of more than four inches aperture,
sired accuracy, unless the apparent magnitude is re-
eans of screens, to that of a fourth or fifth magnitude
necessary in this connection to avoid confounding the
ployed in the observations of the bodies of the solar
those for obtaining fundamental places of the stars.
tions of the Sun, Moon, Mercury and Venus with a
le are, from the unavoidable conditions, necessarily
a degree even beyond the probable error involved in
tions of the large stars. In spite of these unfavorable
however, the continued observations of these bodies
ipal observatories, for many years, have produced the
ble results even when the work on the standard stars,
eir results depend, has no claim whatever to a funda-
acter.

phic exploration the first endeavor is to secure ap-
positions of salient points from a rapid reconnois-
s is followed by more careful work fixing the observ-
with that degree of precision which insures good re-
lly, the highest qualities of skill and science are com-
aust all available means to reach the greatest attain-
y. In the exploration of the heavens, the first two of
have already been taken, and most of the stars of the
itudes have been so well observed, that the accuracy
itions is not only far higher than is required by the
ll of the navigator, but it is equal to all the demands
practical work. It is the next step which challenges
he mechanician, the observer and the computer; and
s cannot rest at ease until all known resources have

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d from page 126.

been exhausted in the attempt to reach the best results. It is not a very difficult matter to fix the position of stars within a range, in the individual observations, of three or four seconds of arc, but that degree of accuracy is not sufficient for the more exact problems of astronomy, and it falls far short of what is required in the important discussions of solar and stellar motions.

Bradley's observations furnished the data for Bessel's Fundamenta Astronomiæ and many astronomers have since attempted by reductions to obtain improved positions for Bradley's stars. The value of these observations in the development of modern astronomy can hardly be exaggerated. Their importance in the determination of stellar proper motions increases with the lapse o time; and yet, the accuracy of the original observations was fa inferior to that obtained in ordinary routine work with moder methods and improved instruments.

Fundamental Catalogues of stars have notably increased sinc the Fundamenta Astronomiæ, but the demand has not yet bee satisfied. The catalogues of declinations or north-polar distances are more numerous than those of right ascension, evidently because, for many reasons, independent declinations ar more readily determined.

There is probably no collection of the right ascension of th large stars that has attained, or justly deserved, a higher reputation than the Pulkowa Catalogue. The observations on whic this catalogue is founded were made by Schweizer, Fuss, Lindhagen and Wagner, at the Pulkowa observatory between 184 and 1853. The observations were reduced by the several observers, thoroughly discussed by Wagner and published in 1869 Only one observer was employed at any period. As these result have received high praise for their accuracy and for their freedo from systematic errors, it may be of some interest to conside briefly, and in a general way, the character of the data on whic the results depend.

The objective of the transit instrument with which these observations were made, had a focal length of 8 feet and 6 inches an a diameter of 5.85 inches. It was so constructed that the ocula and the objective could be interchanged. It was also reversibl and a part of the observations were made with the clamp eas and the remainder with the clamp west. This construction permitted the observations to be made under four different sets o conditions, and for that reason the observed right ascensions o each star were arranged, for facility of discussion, in four separate groups.

ination of the results in each group discloses some in-
acts that are worth considering somewhat in detail.
number of stars in the catalogue that are reckoned as
tars, and are south of 70° north declination, is 365.
nber seventy per cent have a range, in the individual re-
least one of the four groups, of two-tenths, or more,
d of time. This range is between $0^s.20$ and $0^s.29$ for
between $0^s.30$ and $0^s.39$ for 92 stars; between $0^s.40$
or 15 stars, and $0^s.50$ or more for 6 stars. The mean
he 255 stars is $0^s.297$. In general, the accordance be-
individual results is quite good but the discordance
oned sometimes occurs more than once in the collected
ns of the same star, and these doubtful data have been
lucing the standard places given in the catalogue. It
ssary to look for minor discrepancies, for enough of ap-
nagnitude have been cited already to warrant the con-
at better observing can, and ought to be done with
struments and that the needs of astronomical science
nand a more comprehensive, and a more accurate, stan-
ogue of right ascensions.

narks must not be interpreted as unfavorable criticism
owa catalogue, by far the best work of its period, but
ade simply to call attention to the fact, that the pres-
f stellar astronomy and the direction which the inves-
of the immediate future are likely to take, plainly re-
nost accurate fundamental catalogue of the standard
modern instruments and appliances, modern methods
ost skilful observers can produce. All of these condi-
ssential and they must be carefully coördinated to ob-
sired results.

be plain to every astronomer that the needed funda-
talogue must be deduced from new observations.
tion and discussion of old observations of doubtful
a waste of time and energy. Under existing circum-
e greatest weight must be given to the observations.
nount of labor nor skill in computation can derive re-
desired accuracy from careless, incomplete or incorrect
ns. An attempt on the part of the computer to apply
n of theoretical weights, either simple or complex, to
vations is almost certain to lead, at least, to self decep-
the safe as well as reasonable rule in such case would
he weight zero.

nple may serve to illustrate the effect of dealing contin-

uously with old observations. In standard star positions th
four principal national ephemerides are not only not in accor
with each other, but they generally do not exhibit results, eve
from the few best modern observations. The many discrepan
cies, of varying magnitude, in these volumes, present with marke
emphasis the undesirable results arising from the custom o
"threshing old straw."

The data on which these several ephemerides are founded ar
the common property of all astronomers, and no one can clai
the exclusive use of any published observations; and yet nationa
pride or national obstinacy, which is sometimes mistaken for th
nobler sentiment, or some computer's pet scheme or system o
combination, has led to the adoption of a variety of assumption
in the interpretation and treatment of the original data, unti
our standard ephemerides are so complex in their structure tha
the exact details of their preparation are practically unknow
outside their respective computing offices. The accuracy of th
star positions is unchecked by any recent fundamental observa
tions, and they lack that trustworthy character that should in
here in a system intended to serve as a basis for even good differ
ential work.

If this character were wholly satisfactory, we should soon se
the representatives of Astronomy, Geodesy and Geology gather
ing about the zenith telescope, confident of reaching, by the sys
tematic use of this simple instrument, some definite conclusion i
regard to the variation of terrestrial latitudes. But the accurat
star positions do not exist, and under the present conditions th
most feasible plan for utilizing this instrument is to arrange th
observing stations so as to eliminate the effect of errors in th
star places.

If it be admitted that sidereal astronomy is worthy of furthe
and more accurate study, that the needs of astronomical researc
at the present time and in the immediate future demand more ex
act positions of the standard stars, it may be desirable to con
sider briefly the status of those agencies to which we must loo
for the successful prosecution of such an investigation.

POSSIBILITIES OF THE TELESCOPE.*

ALVAN G. CLARK.

ion sometimes asked is: "Will not a great increase in lenses necessitate so much increase in thickness that a unt of light will be lost by absorption?" In reply, I , that we are a long way from experiencing anything us in this respect. The forty inch discs, already menve only a combined thickness of some four inches, and of an object-glass of even six feet aperture would e a combined thickness of not more than six inches. To is increased thickness means some more absorption, but e extent that some suppose, especially with the best obtainable.

eriment made at my manufactory will perhaps best just what I mean. I took a block of dense flint glass s thick and polished on both edges. Behind this was nmon newspaper print, while in front of it sat a party narily, although not invariably, used glasses in reading. this nine inches of dense glass, however, he was able ct ease to read the whole newspaper article by lampwithout optical aid. But this nine inches in thickness ve already said, much more than is necessary for even lens, and who knows how soon still more transparent be at hand, considering the steady improvement made ne, and the fact that the present discs are infinitely o the early ones.

n supposing a slightly larger per cent of light is lost by n per unit of surface in a six foot lens than in a three yet the area of the larger will be four times that of the o that the total amount of light must be vastly greater. everyone who has had experience in using telescopes at even if two instruments of quite different sizes can he same object without trouble, the larger one has a deantage from the greater amount of light and the consereased ease and facility of seeing; which enables us to do rk. In illustration of the great light-collecting power telescope, I may cite the fact that with the thirty-six ctor, eighteen nebulæ were discovered at the Lick Obsera space only 16′ by 5′.5, and more recently, a fifth satelen added to the planet Jupiter.

rds the possible bending of great lenses under their own lthough this sometimes occurs in a small degree, both affected in a nearly compensatory manner, while in a ere is no such compensation. Any slight imperfection oint on the surface of the lens, whether from defective ship or bending of the lens itself, produces much less e image than in the case of a reflector. The slightest

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t from article in January *North American Review*.

imperfection of workmanship or distortion of the mirror fron its own weight, as well as any difference of temperature betwee the front and back, will utterly ruin the image, while the pe formance of a lens would be much less affected by the same ci cumstances. Partly for this reason, reflecting telescopes ver rarely give any such definition as refractors.

Then again, the refractor will give a much larger per cent the incident light than the speculum metal reflector. I speak speculum metal reflectors because the difficulty of preserving th reflecting silver film on large silvered glass mirrors is so grea and the process of resilvering becomes so formidable, that I b lieve them to be impracticable.

From what I have said, as well as from other consideration which it is not necessary to mention here, I have not the slighte doubt that our future advance must be along the line of the r fracting telescope.

Until a comparatively recent date wooden tubes were used fo telescopes, but these being sluggish as regards equalization temperature, a star image was often defective and showed wing before all the parts of the telescope had acquired the same ten perature. This defect, however, has been completely eliminate by the introduction of the metallic tube, which, with a minimu amount of weight, gives a maximum amount of stiffness an produces uniformity of temperature very rapidly.

But, in order that the object-glass, as its size becomes so grea should also rapidly assume and constantly maintain uniformit of temperature in all parts, I have separated the crown and fli lenses in construction so as to allow a free circulation of air b tween them. In the Lick telescope this separation amounts t some six inches with holes in the sides of the cell, thus allowin a free circulation of air between the lenses.

Thus we have to-day a refracting telescope that has steadi grown in size with increasing perfection in all its parts, an which has, beyond question, a still greater future before it. Wha the pledge of the past has been, the future will fulfil. What, the are the possibilities of accomplishment for these great telescop of the future?

We may answer that they will do great work anywhere, a though much depends on the circumstances in which they a placed. For the finest work they should have good atmospher conditions, but these may be obtained at various places throug out the world, both at ordinary as well as higher altitudes. Whe used under such conditions much will be added to our prese knowledge of astronomy.

The great and rapid strides which have lately been made astro-physics, principally in the line of photometry, photograph and spectroscopy, added to the vast amount of work which w always remain to be done in the older astronomy of motio opens a field for the most powerful means of research. The monster telescopes may be characterized as the great ligh collectors and space-penetrators of the universe, and the province, the solution of the ultimate problems of science.

Astro-Physics.

NEW TABLE OF STANDARD WAVE-LENGTHS.*

HENRY A. ROWLAND.

the last ten years I have made many observations of
ths, and have published a preliminary and a final table
ave-lengths of several hundred lines in the solar spec-

purpose of a new table I have worked over all my old
ons, besides many thousand new ones, principally made
graphs, and have added measurements of metallic lines
ake the number of standards nearly one thousand.
all the new measurements have been made on a new
machine whose screw was specially made by my pro-
rrespond with the plates and to measure wave-lengths
h only a small correction.
v measures were made by Mr. L. E. Jewell, who has
me so expert as to have the probable error of one set-
t $\frac{1}{1000}$ division of Angström, or 1 part in 5000000 of
-length. Many of these observations, however, being
different measuring instruments, and before such ex-
ad been obtained, have a greater probable error. This
ly true of those measurements made with eye observa-
he spectrum direct. The reductions of the reading were
nyself.
ratings of 6 in. diameter and 21½ ft. radius were used;
oservations were extended over about ten years.
ndard wave-length was obtained as follows: Dr. Bell's
D_1 was first slightly corrected and became 5896.20.
ce's value of the same line was corrected as the result
easurements made on his grating and became 5896.20.
s of the wave-length then become

ight	*Observer*	*D.*
1	Angström, corrected by Thalen..........	5895.81
2	Müller & Kempf..................................	5896.25
2	Kurlbaum...	5895.90
5	Peirce	5896.20
0	Bell..	5896.20
	Mean...	5896.156

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nicated by the author.
cyc. Brit., **Art.** *Screw.*

As the relative values are more important for spectroscopic work than the absolute, I take this value without further remark. It was utilized as follows:

1st. By the method of coincidences with the concave grating, the wave-lengths of 14 more lines throughout the visible spectrum were determined from this with great accuracy for primary standards.

2d. The solar standards were measured from one end of the spectrum to the other many times; and a curve of error drawn to correct to these primary standards.

3d. Flat gratings were also used.

4th. Measurements of photographic plates from 10 to 19 inches long were made. These plates had upon them two portions of the solar spectrum of different orders. Thus the blue, violet and ultra-violet spectra were compared with the visible spectrum, giving many checks on the first series of standards.

5th. Measurements were made of photographic plates having the solar spectrum in coincidence with metallic spectra, often of three orders, thus giving the relative wave-lengths of three points in the spectrum.

Often the same line in the ultra-violet had its wave-length determined by two different routes back to two different lines of the visible spectrum. The agreement of these to $\frac{1}{100}$ division of Angström in nearly every case showed the accuracy of the work.

6th. Finally, the important lines had from 10 to 20 measurements on them, connecting them with their neighbors and many points in the spectrum, both visible and invisible; and the mean values bound the whole system together so intimately that no changes could be made in any part without changing the whole.

This unique way of working has resulted in a table of wave-lengths from 2100. to 7700 whose accuracy might be estimated as follows:

Distribute less than $\frac{1}{100}$ division of Angström properly throughout the table as a correction, and it will become perfect within the limits 2400 and 7000.

The above is only a sketch of the methods used. The complete details of the work are ready for publication but I have not yet found any journal or society willing to undertake it.

DESCRIPTION OF THE TABLE.

The first column gives the name of the element whose wave-length has been measured. If a letter stands at the left, it is the

' of the line in the solar spectrum. An ? mark after an
means that it is doubtful if the line is really due to the
named. If two elements are given *on the same line* (*e. g.*
v. l. 3295.957), it is to be understood that they have ap-
coinciding lines at that particular wave-length. If two
elements are bracketed

$$e.\,g., \left.\begin{matrix}\text{Mn}\\ \text{Ti}\\ \text{Fe}\end{matrix}\right\}\ \text{w. l. } 5260.384$$

; that the first one has a line coinciding with one side of
esponding line in the solar spectrum, the second one has
inciding with the middle, etc., and the appearance of the
e itself is given in a later column. An ? standing alone
that the element which corresponds to the given wave-
; unknown.

econd column gives the intensity of the line in the arc-
n; the third its appearance, and the fourth and fifth do
e for the line in the solar spectrum. R stands for "re-
' d, double; t, triple; ?, doubtful or difficult. The size
umber indicates to some extent the intensity of the line.
ance the intensity 10 means that the line is apparently
; as intense as the intensity 1. Measurements, of inten-
eye-observations, direct or on photographic plates, are
e most uncertain. And so the figures given are estimates
o not apply to comparisons of different portions of the
n, but which are intended to give some idea of the rela-
cts. The intensity of some lines in the arc-spectrum of a
bstance, *e. g.*, Ca, is often so much greater than that of
rs, that the absence of some lines in the solar spectrum is
nderstood. The sixth column gives the character of the
d. M means that the line is a standard in the arc-spec-
⊙ means that the line is an ordinary solar standard; ⊙′,
solar standard; ⊙″, a remarkably good solar standard;
a rather poor solar standard.

ext two columns give the "weights" to be attached to
es of the wave-lengths as standards in the arc and solar
respectively.

st two columns give the final values of the wave-lengths
ed in Angström units, *i. e.*, in ten millionths of a milli-
ordinary air at about 20° C. and 760 mm. pressure.
marked J, are by Mr. Jewell.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Sr	2				M	1		2152.912	
Sr	3				M	1		2165.990	
Si	2				M	2		2208.060	
Si	3				M	2		2210.939	
Si	2				M	2		2211.759	
Si	4				M	2		2216.760	
Si	2				M	2		2218.146	
Al	3				M	2		2263.507	
Al	4				M	2		2269.161	
Sr	10	R			M	1		2275.376	
Ca	20	R			M	3		2275.602	
Fe?					M	2		2298.246	
Ba	20	R			M	1		2304.364	
Ba	20	R			M	1		2335.267	
Fe					M	2		2343.571	
Fe					M	2		2348.385	
Fe					M	2		2364.897	
Al	6				M	3		2367.144	
Al	7				M	3		2373.213	
Fe					M	2		2373.771	
Fe?					M	3		2382.122	
Fe					M	2		2388.710	
Fe?					M	3		2395.715	
Ca	25	R			M	5		2398.667	
Fe					M	2		2399.328	
Fe					M	2		2404.971	
Fe					M	2		2406.743	
Fe					M	2		2410.604	
Si	8				M	15		2435.247	
Si	3				M	10		2438.864	
Si	3				M	10		2443.460	
Fe?					M	3		2447.785	
Si	3				M	10		2452.219	
Fe?					M	3		2457.680	
Fe					M	3		2462.743	
Fe					M	3		2472.974	
C*	10				M	15		2478.661	
Fe					M	3		2479.871	
Fe					M	3		2483.359	
Fe					M	3		2484.283	
Fe					M	3		2488.238	
Fe					M	3		2489.838	
Fe					M	3		2490.723	
Fe					M	3		2491.244	
Bo	15				M	20		2496.867	
Bo	20				M	20		2497.821	
Fe					M	3		2501.223	
Si	10				M	15		2506.994	
Fe					M	3		2510.934	
Si	7				M	10		2514.417	
Si	15				M	7		2516.210	
Fe					M	3		2518.188	

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* This line seems to be the only single line of carbon not belonging to a band in the arc spectrum. It was determined to belong to carbon by the spark spectrum (R).

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
Inten-sity.	Appear-ance.	Inten-sity.	Appear-ance.		In Arc.	In Sun.		
8				M	10		2519.297	
				M	3		2522.948	
9				M	10		2524.206	
				M	3		2527.530	
10				M	5		2528.599	
				M	3		2535.699	
50	R			M	2		2536.648	
				M	3		2541.058	
				M	3		2546.068	
				M	2		2549.704	
10				M	5		2568.085	
10				M	5		2575.198	
				M	2		2576.195	
				M	2		2584.629	
				M	2		2585.963	
				M	2		2593.810	
				M	2		2598.460	
	R			M	3		2599.494	
				M	2		2611.965	
				M	3		2631.125	
5				M	7		2631.392	
				M	3		2679.148	
				M	2		2706.684	
				M	3		2719.119	
				M	3		2720.989	
5				M	1		2721.762	
				M	3		2723.668	
				M	3		2733.673	
				M	3		2737.405	
				M	3		2742.485	
				M	3		2750.237	
				M	2		2755.837	
				M	3		2756.427	
				M	2		2761.876	
				M	2		2762.110	
				M	2		2767.630	
				M	2		2772.206	
5	R			M	5		2776.798	
				M	2		2778.340	
5	R			M	3		2778.381	
8	R			M	5		2779.935	
5	R			M	5		2781.521	
				M	1		2781.945	
5	R			M	5		2783.077	
				M	3		2788.201	
				M	3		2794.911	
20	R			M	12		2795.632	
				M	3		2798.369	
				M	3		2801.183	
20	R			M	10		2802.805	
5				M	3		2813.388	
3				M	1		2823.389	

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ine shows as a sharp reversal, with no shading, in the spectra of all
tried, that contained any trace of continuous spectrum in this region (J).
arkable symmetrical group of five lines in the spectrum of magnesium.

Element	In Arc. Intensity	In Arc. Appearance	In Sun. Intensity	In Sun. Appearance	Kind of Standard	Weight In Arc	Weight In Sun	Wave-length in Arc	Wave-length in Sun
Fe	5				M	1		2825.667	
Fe	4				M	7		2832.545	
Fe	3				M	1		2838.226	
Fe	3				M	1		2843.744	
Fe	5				M	7		2844.085	
Fe	6				M	5		2851.914	
Mg	100	R			M	15		2852.239	
Si	15				M	12		2881.695	
Fe	7	R			M	3		2912.275	
Fe	8	R			M	3		2926.127	
Fe	10	R			M	4		2937.020	
Fe	8	R			M	4		2947.993	
Fe	7	R			M	4		2954.058	
Fe	5				M	3		2957.485	
Fe	5				M	3		2965.381	
Fe					M	1		2966.985	
Fe	8	R			M	12		2967.016	
Fe	4	R			M	7		2970.223	
Fe	6	R			M	7		2973.254	
Fe	12	R			M	15		2973.358	
Fe	2				M	6		2981.570	
Fe	10	R			M	15		2983.689	
Fe					M	1		2987.410	
Si	4				M	5		2987.766	
Fe	8	R			M	18		2994.547	
Ca	7	R			M	3		2995.074	
Ca	10	R			M	3		2997.430	
Fe	4	R			M	5		2999.632	
Ca	6	R			M	3		2999.767	
Ca	8	R			M	3		3000.970	
Fe	8	R			M	15		3001.070	
?			3		⊙	1			3005.160
?			4		⊙	1			3005.404
Ca	15	R			M	3		3006.978	
Fe	2				M	1		3007.260	
Fe	1				M	3		3007.408	
Fe	6	R			M	15		3008.255	
Ca	7	R			M	3		3009.327	
Fe	4	R			M	3		3009.696	
?			4		⊙′	5			3012.557
?			6	d?	⊙′	4			3014.274
Fe			3		M	1		3016.296	
Fe	5				M	1		3017.747	
Fe	5				M	1		3019.109	
Fe					M	1		3019.752	
Fe	10	R			M	15		3020.611	
Fe	25	R			M	18		3020.759	
Fe	15	R			M	18		3021.191	
Fe	7	R	7		M	7		3024.154	
?			5		⊙′		7		3024.475
?			4		⊙′		7		3025.394
Fe	10	R	10		M	7		3025.958	
Fe					M	1		3027.245	
?			5		⊙	7			3035.850
Fe	15	R	15		M	10	2	3037.505	3037.492

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
sity.	Appear-ance.	Inten-sity.	Appear-ance.		In Arc.	In Sun.		
15	R	4		$M\odot_1$	3	2	3044.114	3044.119
10	R	3		⊙′	5			3044.683
				⊙′	1			3016.778
20	R	20		M	13		3047.720	
		3 3	d	⊙″		5		3050.212
		3		⊙′		5		3053.173
		3 3	d	⊙′		1		3053.527
		5	d?	⊙″		5		3055.821
10	R	10		M	8		3057.557	
10	R	10		M	15		3059.200	
		3		⊙′		1		3061.098
8	R	3		M⊙″	1	5	3061.932	3061.930
10	R	10		M	10		3067.363	
6		8		M	3		3075.339	
10	R	10		M	4		3075.849	
		2		M	1		3077.216	
		4		⊙		6		3077.303
		4		⊙″		6		3078.148
4		6		M	3		3078.759	
7		2		⊙″		1		3079.724
		5		⊙″		1		3080.863
20	R	7		M	17		3082.272	
6	R	7		M	5		3083.849	
		4		⊙″		1		3086.891
8	R	8		M	1		3088.137	
20	R	10		M	15		3092.824	
4		2		M	8		3092.962	
		2		⊙′		9		3094.739
1		3		⊙′		9		3095.003
4		7		M	3		3100.064	
4-?		4		M	3		3100.415	
6		6		M	3		3100.779	
20	R	8		M	3		3101.673	
10	R	6		M	3		3101.994	
		2		⊙		1		3106.677
		3		⊙′		1		3109.434
		2		⊙″		3		3115.160
7		5		⊙″		9		3121.275
3		1		⊙′		5		3129.882
10	R	8		M	1		3134.223	
4		2		⊙′		3		3137.441
		3		⊙′		5		3140.869
		2		⊙′		3		3153.870
		8		M	1	1	3158.994	3158.988
		1		⊙′		5		3167.290
		5		⊙″		1		3172.175
1		1		⊙′		5		3176.104
4	N	4		⊙′		5		3188.164
3		3		M	1	1	3195.729	3195.702
10	R	4		M⊙″	1	5	3200.040	3200.032

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is a very faint line on the violet side in the solar spectrum.
is a line towards the red, also.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-lengt in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		5		M	1		3214.152	
Ti	4		3		⊙″		6		3218.390
Fe			6		⊙′		1		3219.697
Fe			6		⊙′		1		3219.909
Fe?	6		5	d	M⊙	3	1	3222.197	3222.203
?	?		7						
Ti	6		4		⊙″		3		3224.368
Fe	8		8		M	3	1	3225.907	3225.923
Ti	5		5		⊙″		1		3231.421
?	?								
Ti	6		4		⊙		12		3232.404
Ti	10	R	8		M	1	1	3236.696	3236.697
?			6		⊙″		12		3246.124
Fe									
Cu	40	R	9		M⊙$_1$	15	5	3247.671	3247.680
Mn	4		4		⊙′		10		3260.384
Ti	3								
Fe	1								
Va	10		4		⊙″		10		3267.839
Cu	30	R	6		M⊙″	15	5	3274.090	3274.092
Ti	6		5		⊙″		9		3287.791
Fe	5		5	d?	⊙″		10		3292.174
Co–T	4 7								
Mn–Di	3 2		4		⊙″		9		3295.957
Na	15	R	6		M⊙″	1	6	3302.504	3302.501
Na*	10	R	5		M⊙$_1$	1	6	3303.119	3303.107
?			3	d	⊙′		10		3303.648
Fe			3						
Fe†	10		7		M⊙$_1$	1	5	3306.119	3306.117
Fe‡	10		7		M⊙$_1$	1	5	3306.481	3306.471
Mn	2		1	d	⊙″		10		3308.928
Co–Ti	3 6		4						
Ti	5		5		⊙″		10		3318.163
Fe	2		2		⊙′		8		3331.741
Cr	3		3	d	⊙′		9		3348.011
Fe	3		3						
Fe	2		2		⊙′		9		3351.877
Zr	4		1		⊙″		8		3356.222
Ti§	5		3	d	⊙″		9		3377.667
Ti	5		3						
Fe	2		2		⊙″	1	12	3389.913	3389.887
Co	10	R	3	d	⊙′	1	12	3405.255	3405.272
Ti	1		3						
Fe	2		1		⊙′	1	18	3406.602	3406.581
Fe	5		4		⊙′	1	18	3406.965	3406.955
?			2		⊙″		15		3425.721
Fe‖	6		5		M	2	1	3427.279	3427.282
Fe	15	R	15		M⊙$_1$	7	4	3440.756	3440.759

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[*] Red component of a double which has a Zn line between. There is anoth Zn line at about 3302.7 in the solar spectrum.

[†] Second line from red side of a group of five lines.

[‡] Second line from violet side of a group of four lines.

[§] A very wide nebulous line of Ba comes here.

[‖] Red component of a double (the other line being also Fe) having anoth fainter line at the red edge.

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
sity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
o		10		M$\odot_1$	6	4	3441.135	3441.135
8	R	8		M$\odot_1$	6	4	3444.024	3444.032
6	R	4		⊙″		10		3455.384
8		3		⊙″		8		3464.609
o	R	4	d	M	7	3	3466.010	3465.991
o	R	6						
o	R	10		M	7	3	3475.602	3475.594
7	R	8		M	5	2	3476.848	3476.831
2								
3		4		⊙″		10		3478.001
2								
4	R	5		⊙′		9		3486.036
o	R	10		M	7	3	3490.724	3490.721
4	R	4		⊙″		8		3491.464
?								
5		5		M	1	1	3497.266	3497.264
6	R	7	d	M	5	4	3497.991	3497.991
?		3						
2		3		⊙″		4		3500.721
7	R	7		⊙″		4		3500.993
5		4		⊙′		8		3510.987
7	R	6		M	2	3	3513.981	3513.947
6	R	5		⊙″		10		3518.487
o	R			M	1		3519.342	
5	R	7		M	6	5	3521.409	3521.404
o	R			M	1		3529.547	
3		5		⊙″		10		3540.266
		4		⊙″		6		3545.333
6		2		M⊙″	1	1	3549.147	3549.145
2		3		⊙″		7		3550.006
9	R	8		M⊙	3	4	3558.674	3558.670
2								
1		4	d?	⊙″		12		3564.680
o	R	12		M	6	4	3565.530	3565.528
o	R	20		M	8	4	3570.253	3570.225
o		10		M	1	1	3570.412	3570.402
o	R	40		M$\odot_1$	9	6	3581.344	3581.344
2		4		⊙″		12		3583.483
6		2		M	1	1	3584.662	3584.662
2		1		M	8		3585.992	
		2		M	2		3586.041	
		3		M	7		3590.523	
5		4		⊙″		12		3597.192

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tal measured was Fe.
est line of group of six lines.
e strongest line in a group of six lines.
s a Co line near this towards the red.
nponent of a double.
omponent of a double. Other component was not measured.
g compound bismuth line comes here also.
omponent of a double.
nponent of a double with another Fe line towards the red.
ne in the second head of the carbon band.
ne in the first head of carbon band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-lengt in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Yt (Fe)	10–?		4		M⊙″	1	1	3600.884	3600.880
Yt	6		2		M⊙	1	1	3602.065	3602.061
Cr*	10	R	4		M$\odot_1$	1	2	3605.497	3605.483
Fe*	5		7	d	M$\odot_1$	2	2	3605.621	3605.635
Fe†	4		6		M	2	2	3606.836	3606.831
Fe	15	R	15		M⊙	11	10	3609.015	3609.015
Yt	7		3		M⊙	1	1	3611.196	3611.193
Fe	4		4		⊙′	1	15	3612.237	3612.217
Ca ‡			2	d	M$\odot_1$	1	1	3617.939	3617.920
Fe	4		3						
Fe	20	R	20		M$\odot_1$	11	10	3618.922	3618.924
Yt	3		1		M	1	1	3621.096	3621.122
Fe	4		4		M⊙	2	2	3621.616	3621.606
Fe	4		4		M$\odot_1$	2	3	3622.161	3622.147
Fe	4		4		M⊙″	1	14	3623.338	3623.332
Fe§	2		3		⊙″		10		3623.603
Yt	3		2		M⊙	1	1	3628.853	3628.853
Fe	20	R	20		M$\odot_1$	11	10	3631.616	3631.619
Yt‖	5		3	d	M	1	1	3633.277	3633.259
Ti	10	R	3		M⊙′	3	1	3635.615	3635.616
Fe	5		5		M$\odot_1$	1	1	3638.454	3638.435
Pb¶	50	R	1		M	4		3639.728	
Cr ‡	2		5		M⊙″	1	14	3640.545	3640.536
Fe	5								
Fe	10	R	10		M⊙	10	11	3647.995	3647.995
Co	5	R	3		⊙″		5		3652.692
Ti	10	R	4		M⊙′	2	7	3653.639	3653.639
Mn	2		2		⊙″		7		3658.688
Fe	2								
Fe	5		3		⊙″		13		3667.397
Fe	8	R	8		M⊙	8	7	3680.064	3680.064
Co **	9		6		⊙″	1	13	3683.209	3683.202
Fe	3								
Va	4								
Pb	60	R	1		M	5		3683.622	
Fe	5		6		⊙″	1	14	3684.268	3684.259
Fe	10	R	8		M⊙	8	6	3687.609	3687.607
Yt			3		M⊙	1	1	3694.351	3694.349
Fe	5		5		⊙″	1	11	3695.208	3695.194
Fe††	7	R	8		M⊙	7	5	3705.715	3705.711
Fe	5		5		⊙″	1	11	3707.201	3707.186
Fe	10	R	10		M$\odot_1$	6	4	3709.395	3709.397
Yt	10		3		M⊙	1	1	3710.442	3710.438

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* In the solar spectrum these belong to a group of several lines. Of the thr most prominent, the middle line is Cr. with possibly a weak line on its red edg and the red one is a close double, the violet component of the double being Fe (J

† The solar line is a group of four lines. The third from the violet side is tl brightest and is Fe.

‡ Metal measured was Fe.

§ There is a faint line on the red side.

‖ Red component of double.

¶ In the solar spectrum this is the red component of a double, the other bein cobalt.

** The metallic line measured was Fe.

†† Violet component of a double.

Arc.	In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
	7		⊙″	1	12	3716.601	3716.585
R	50		M⊙	11	10	3720.082	3720.086
	10	d	M⊙	7	5	3722.712	3722.691
R	7		M	5	3	3727.768	3727.763
	5		⊙″	1	15	3732.549	3732.542
R	7		M⊙	5	3	3733.467	3733.467
R	50		M⊙	8	7	3735.012	3735.014
	3	d	$\odot_1$		2		3736.969
R	5		M$\odot_1$	2	3	3737.081	3737.075
R	30		M⊙	7	8	3737.280	3737.282
	2 6 2	t	M⊙	4	2	3743.506	3743.502
R	10		M	8	6	3745.708	3745.701
R	7		M	6	5	3746.048	3746.054
	7	d	⊙′	1	9	3747.082	3747.095
R	10		M⊙	7	8	3748.410	3748.409
R	20		M⊙	7	8	3749.633	3749.633
	2 1	d	⊙		12		3754.664
	2		⊙′		12		3756.211
R	15		M⊙	8	7	3758.380	3758.379
R	10		M	9	8	3763.939	3763.942
R	8		M⊙	9	8	3767.342	3767.344
	4	d?	⊙		12		3770.130
	3		M⊙	1	1	3774.478	3774.480
R			M	1		3775.869	
	4		⊙′		15		3780.846
	3		⊙′		15		3781.330
R	6		⊙		15		3783.674
R	8		M⊙	3	3	3788.029	3788.032
	3		⊙		15		3794.014
	8		M	3	4	3795.148	3795.150
	7		⊙		2		3798.662
	8		⊙		2		3799.698
	3		⊙″		15		3804.153
	6		⊙″		15		3805.487
R	20		M⊙	4	3	3815.984	3815.985
R	30		M⊙	4	4	3820.566	3820.567
	6		⊙′		10		3821.318
R	5		⊙′		10		3823.651
R	20		M⊙	4	4	3826.024	3826.024
R	8		M	1	1	3827.973	3827.973
R	8		M		2		3829.505
R	10		M		2		3832.446
	4		⊙		8		3836.226
	5	d	M$\odot_1$	1	1	3836.638	3836.652
R	20		M		2		3838.430

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llic line measured was Fe.
tion of broad solar double is composed of three lines, the red line
iddle one Co (J)
Va line towards the violet.
ne of symmetrical group in carbon band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-lengt in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	7	R	7		M	1	2	3840.589	3840.584
Fe	4		5		⊙		8		3843.406
Fe	6		7		M	1	2		3856.517
Fe	10	R	10		M⊙$_1$	2	3	3860.050	3860.048
C*			3		⊙′		8		3864.441
C†			4		M	4	4	3871.527	3871.528
? Va			3		⊙		15		3875.224
C‡			7		M⊙$_1$	5	3	3883.479	3883.472
C§					M⊙$_1$		8	3883.523	3883.548
Cr			1		⊙		12		3883.773
Fe	15	R	9		M⊙$_1$	7	6	3886.421	3886.427
Fe	3		4		⊙′		12		3897.599
Si	10	R	10		M	4	4	3905.670	3905.666
Fe	3		3		⊙′	1	12	3916.886	3916.875
Ti	6		4		⊙′		15		3924.669
Fe Va	1 2		4		⊙′		15		3925.345
Fe	3		4		⊙		13		3925.792
Fe‖ ?	5 ?		4 4	d	⊙′		12		3926.123
Fe	10	R	8		M	1	3	3928.060	3928.071
K Ca¶	75	R	300		M	6	5	3933.809	3933.809
Fe	3		4		⊙′		8		3937.474
Fe–Co	4 4		5		⊙	1	15	3941.034	3941.021
?** Fe	? 5		2 4	d	⊙		15		3942.559
Al	20	R	10		M⊙$_1$	7	7	3944.165	3944.159
Ca††	4		2		M	1	2	3949.070	3949.034
Fe	4		4		⊙″		15		3950.101
Yt	10		2		⊙		13		3950.497
Fe	2		2		⊙′		13		3954.001
Fe–Ca	5 6		6		⊙′	1	2	3957.228	3957.180
Fe	3		3		⊙″		11		3960.429
Al	30	R	15		M⊙$_1$	7	8	3961.680	3961.676
H Ca¶	70	R	200		M	7	5	3968.617	3968.620
H ‡‡					M			3970.05	
Fe§§	5		4		⊙′		11		3971.478
Ca‖‖	5		3	d	M	1	2	3973.881	3973.835
Fe	5		4		⊙″		15		3977.891

* One of the lines in the carbon band.

† Second head of carbon band.

‡ First line of first head of carbon band.

§ Edge of first head of carbon band.

‖ .087 apart.

¶ The solar line is doubly reversed and spread out into broad shading f 6.000 or 7.000 on either side. In each case the second reversal is slightly eccentr with respect to the other or displaced slightly toward the red (J).

** Components .085 apart.

†† Red component of a triple.

‡‡ Value determined by Dr. Ames.

§§ Red component of a double.

‖‖ Red component of double, the violet component being Fe. There is also Ni line close to violet side.

Arc.		In Sun.			Weight.			
sity	Appearance.	Intensity.	Appearance.	Kind of Standard.	In Arc.	In Sun.	Wave-length in Arc.	Wave-length in Sun.
		4		⊙		14		3981.914
		6	d	⊙		9		3984.078
4		7 1	d	⊙		9		3986.003
4 2		6	t	⊙		4		3987.210
1 2		3		⊙		9		4003.910
10		10		⊙		3		4005.305
		3		⊙″		7		4016.578
2 2		4		⊙″		10		4029.796
50	R	7		M	3	4	4030.919	4030.914
25	R	6		M	3	4	4033.230	4033.225
20	R	5		M	3	4	4034.642	4034.641
7		3		M			4035.88	4035.88
50	R	1		M	2	2	4044.301	4044.293
20	R	20		M⊙$_1$	7	7	4045.975	4045.975
40	R	1?		M	2		4047.373	
1								
8		6	d	⊙		13		4048.893
2								
8		5		⊙″		13		4055.701
5		5		⊙″		8		4062.603
15	R	15		M⊙$_1$	7	7	4063.755	4063.756
10		10		M⊙$_1$	7	9	4071.903	4071.904
4		4		⊙″		14		4073.920
50	R	8		M⊙$_1$	5	6	4077.876	4077.883
2 5		2 4	d	⊙		7		4083.767
2		2		⊙		7		4083.928
2		2		⊙″		8		4088.716
3 1		6		⊙″		10		4103.101
5		5	d?	⊙″		12		4107.646
3		4		⊙″		14		4114.600
1 10	R	1 3		⊙	1	12	4121.476	4121.481
3 1		3		⊙′		13		4121.968
4		3		⊙″		17		4157.948
				M			4158.2	
4		3		⊙″		20		4185.063
		1		M⊙	5	6	4197.256	4197.251

nents about .060 apart.
ne shaded to red, shading due to a Mn line on red side.
ine. Central line brightest.
r eight lines. The brightest and most of the others are due to Fe.
omponent of double being itself double or reversed in Sun. The other
s weak.
nponent of double being itself double or reversed in Sun. The other
s weak.
qual double, violet component much the weaker.
line measured.
ne of second head of carbon band.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-leng in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Zr	2								
Fe	5		5		⊙″	2	22	4199.257	4199.263
Fe	8		5		⊙′	2	4	4202.187	4202.188
Fe	2	2			⊙		2		4215.616
				d			18		4215.667
Sr	40	R	4		M⊙	6	3	4215.688	4215.687
C*			1		M⊙	4	2	4216.133	4216.137
Fe	2		4		⊙″	1	22	4222.396	4222.381
g Ca	50	R	10		M⊙	9	10	4226.898	4226.892
Fe	4		5		⊙′	1	1	4250.300	4250.290
Fe	5		7		⊙′	4	3	4250.949	4250.956
Cr	20	R	7		M⊙″	2	15	4254.494	4254.502
Fe	6	R	7		⊙	4	3	4260.647	4260.638
?	?		1	d	⊙		12		4267.958
Fe	1		2						
Fe	10	R	8		M⊙	8	9	4271.920	4271.924
Cr	15	R	5		M⊙	1	2	4274.954	4274.958
Ca	5	R	3		M⊙	2	4	4283.175	4283.170
Ca	4	R	3		M⊙	3	5	4289.527	4289.523
Cr	10	R	4		M⊙	2	2	4289.884	4289.881
?			4	d	⊙′		14		4293.249
Ca	3	R	2		M⊙	3	5	4299.153	4299.152
Ca	6	R	4		M	5	7	4302.690	4302.689
Sr	8		2		M	1		4305.636	
Ti	10	R	4		M⊙	4	4	4306.071	4306.071
Ca	4	R	2		⊙	3	3	4307.906	4307.904
G				d	⊙		3		4308.034
Fe	7	R	5		⊙	8	10	4308.072	4308.071
Ca	4	R	3		M⊙″	3	16	4318.816	4318.818
f Fe	10	R	8		M⊙′	8	15	4325.932	4325.940
Cr	2		1	d?	⊙		11		4343.387
Fe	2		2						
Fe	4		3		⊙″	1	17	4352.908	4352.903
Ni	3		1						
Cr	4		3	t	⊙		10		4359.778
Zr	5		1						
Fe	4		5		⊙″	1	14	4369.948	4369.943
Fe	5		5		⊙″	1	17	4376.108	4376.103
d Fe	15	R	10		M⊙′	10	11	4383.721	4383.721
Fe †	2		3		⊙		14		4391.149
Ti	1		1						
Fe	10	R	8		M⊙	10	11	4404.928	4404.927
Va	9	R	2	d	⊙		19		4407.850
Fe	3		3						
Cd	6		6		M	3		4413.181	
Fe	4	R	4		M⊙	9	7	4415.298	4415.299
Ca	5	R	4		M⊙″	5	7	4425.616	4425.609
Ca	5	R	4		M⊙	5	5	4435.133	4435.132
Ca	4	R	3		M⊙″	5	6	4435.856	4435.852
Fe‡	8		5		⊙″	2	18	4447.912	4447.899
Ca§	6	R	6		M⊙$_1$	6	6	4454.949	4454.950

* First line in first head of carbon band.

† Unequal double, components being about .050 apart.

‡ There is a faint side line to red.

§ There is a faint line close to violet.

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
sity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
3	R	2		M	5	3	4456.055	4456.047
1		1		M$\odot_1$	2	2	4456.791	4456.793
		5		$\odot''$	1	18	4494.756	4494.735
5 2		4 1		$\odot_1$		14		4497.041
		2	d	$\odot''$		8		4499.070
		1		$\odot'$		7		4499.315
6		5		$\odot'$		18		4501.444
							4502.6	
		4		$\odot''$		17		4508.456
				M	4		4511.474	
				M	3		4513.883	
70	R	7		M$\odot''$	6	8	4554.212	4554.213
4		6		$\odot''$		13		4563.939
3		5		$\odot''$	1	14	4571.281	4571.277
5		6		$\odot''$		14		4572.157
1	N	4		$\odot''$	1	14	4578.807	4578.731
		4		$\odot''$		14		4588.384
		4		$\odot''$		15		4590.129
2		4		$\odot''$		20		4602.183
50	R			M	1		4602.25	
							4606.6	
50	R	2		M$\odot'$	5	4	4607.506	4607.509
? 4		2 6	d	$\odot_1$		11		4611.453
4 5		5		$\odot'$		13		4629.515
3		4		$\odot'$		14		4637.683
3		4		$\odot'$		14		4638.194
2		4		$\odot''$		17		4643.645
6	R	3		M$\odot$	1	1	4648.833	4648.835
? 3		2 5	d	$\odot'$		11		4668.303
		4?		M	3	3	4678.339	4678.353
3		6		$\odot'$		12		4679.028
		2		M	1		4680.319	
2		3		$\odot''$		13		4683.743
4		4		$\odot''$		12		4686.395
		4		$\odot'$		14		4690.324
3 3		2 4	d	$\odot_1$		11		4691.581
5		9		$\odot''$	1	11	4703.249	4703.180
3		3		$\odot''$		13		4703.986
9	R	6	d?	M$\odot$	1	1	4714.598	4714.599
4		4		M$\odot''$	2	2	4722.339	4722.349
2 7		4 3	d	$\odot$		11		4727.628

mponent of a double. Other line is Mn.
ne in first head of blue carbon band.
line with fine line very close to violet and another farther to violet.
s the double line measured there is another fine line near the red side.
g. line is of the nature of a band, shaded toward the red. It coincides
ar line when there is very little material in the arc (R).
ine is shaded towards the violet, probably owing to a close side line.
the same in character as the red lithium line (J)

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-lengt in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Mn	15	R	6		⊙″		11		4754.226
Mn	10	R	6		M⊙″	1	1	4783.607	4783.601
Cd			?		M	3		4800.097	
?	?		1	d	$\odot_1$		3		4805.253
Ti	1		4						
Zn			3		M⊙″	1	1	4810.725	4810.723
Mn	10		6		M⊙″	1	12	4823.715	4823.697
Fe?			4		⊙″		11		4824.325
Fe	4		5		⊙″		14		4859.934
F H			15		⊙′		5		4861.496
Fe	7		7		⊙″		11		4890.945
Ti*	4		2	d	⊙′		11		4900.098
Yt*			2		⊙′		11		4900.306
Cr	2		6	d?	⊙″		14		4903.488
Fe	5								
Pb					M	1		4905.634	
Fe	6		7		⊙″		4		4919.183
Fe†	9		9		M⊙″	1	7	4920.676	4920.682
Fe	2		4		⊙″		13		4924.109
Fe	3		2		⊙″		12		4924.955
Ba‡	60		7	d?	M⊙	1	10	4934.237	4934.247
Fe			6		$M\odot_1$		3		4957.482
Fe			8		$M\odot_1$		3		4957.786
Neb**								4959.02	
Ti	1		3		⊙″		10		4973.274
Fe	3								
? §			1	d?	⊙″		8		4978.782
Fe	3		3						
Ni §	5		3	d	⊙		5		4980.362
?	?		1						
Ti	10		4		⊙	1	10	4981.893	4981.915
Fe	3		4		⊙″		7		4994.316
Ti-La‖	10 10	R N	4		M⊙		8	4999.668	4999.693
Pb					M	5		5005.634	
Fe	3		4		⊙′		10		5005.904
Fe¶			6		⊙″		8		5006.303
Ti	10	R	4	d	⊙″		10		5007.431
Fe	3		3						
Neb**								5007.05	
Mg b′d††					M	3	10	5007.473	
(Ni) Ti	?10		3	d	M⊙′		10	5014.412	5014.422
Ti	5		4						
Ti	7		3		⊙′		8		5020.210
Ti	6		3	d	⊙′		8		5036.113
Ni	3		2						
Ca	3	N	2		M	2	1	5041.867	5041.795

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* A Ba line comes between these and does not coincide with either.

† Shaded, and has a faint line to red.

‡ A very difficult double with a fine line towards the violet (J).

§ There is a faint line to red.

‖ Ti line was measured.

¶ There is a faint side line to violet.

** Values determined by J. E. Keeler from his measurements at the Lick Observatory using the values of the Pb., Fe. and Mg. lines given in this table.

†† Commencement of the head of Mg band.

ts.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Inten-sity.	Appear-ance.	Inten-sity.	Appear-ance.		In Arc.	In Sun.		
	5		5		$\odot''$		12		5050.008
	2		2		$\odot'$		15		5060.252
	10		3		$\odot'$		12		5064.833
	4		4		$\odot''$		14		5068.946
	4		3		$\odot''$		9		5083.525
			?		M	1		5086.001	
	3		2		$\odot''$		9		5090.959
	3		2		$\odot_1$		7		5097.176
u)	3?		3		$\odot''$		12		5105.719
	3		2		$\odot''$		11		5109.825
	? 4		2 3	d	$\odot'$		11		5110.570
	5		2		$\odot''$		9		5115.558
	2 3		1 3	d	$\odot_1$		9		5121.797
	3		2		$\odot''$		9		5126.369
	4		4		$\odot''$		9		5127.530
	1 ?		6	d	$\odot''$		12		5133.871
	4		6		$\odot$		4		5139.437
				d	$\odot$		4		5139.539
	5		6		$\odot$		4		5139.645
	2		3		$\odot''$		5		5141.916
	5		2		$\odot_1$		1		5142.967
				d	$\odot_1$		5		5143.042
	3		4		$\odot_1$		2		5143.106
	5 ?		3		$\odot''$		10		5146.664
	4 2		3 1	d	$\odot$		9		5151.026
5?			2		$\odot''$		10		5154.237
	6		2		$\odot''$		10		5155.937
			2		$\odot''$		11		5159.240
	4		4		$\odot''$		13		5162.448
			1		M	2	1	5165.241	5165.190
	2		2		$\odot''$		10		5165.588
	20	R	8		M$\odot_1$	2	3	5167.488	5167.501
				d	$\odot$		7		5167.572
	6		6		M$\odot_1$	2	3	5167.664	5167.686
	3		4		$\odot''$		3		5169.066
				d	$\odot''$		5		5169.161
	3		4		$\odot''$		3		5169.218
	5		5		$\odot''$		11		5171.783
	35	R	10		M$\odot''$	2	9	5172.866	5172.871

he fine line near to violet belongs to Ni?.
here is a Cr. line near to red.
he Mn line is a faint side line toward the red from the Fe line.
leasurements in the arc spectrum were on the first line of the first head of en carbon band; measurements in the solar spectrum were probably on the st of a group of faint lines near the head of carbon band (J). Much of d can be seen on my map of the solar spectrum extending to the left (R).
omponents about 0.180 apart on photographic plates (J).
omponents about 0.138 apart as measured by Rowland in solar spectrum 050 apart as measured on photographic plates (J).

Elements.	In Arc. Intensity.	In Arc. Appearance.	In Sun. Intensity.	In Sun. Appearance.	Kind of Standard.	Weight. In Arc.	Weight. In Sun.	Wave-length in Arc.	Wave-length in Sun.
Ti	10	R	3		⊙"		11		[illegible]
b_1 Mg	40	R	20		M⊙"	2	11	5183.791	[illegible]
Ti *	2		4		⊙"		3		[illegible]
				d	⊙"		7		[illegible]
Ca	6		4		M⊙"	1	3	[illegible]	[illegible]
Ti	8		3		M⊙"	2	8	5193.134	[illegible]
Fe	3		4		⊙"		10		[illegible]
?	?		2	d	⊙"		11		5202.483
Fe	4		3						
Cr	8	R	4	d	⊙"		10		5204.708
Fe	3		3						
Ti	10	R	3		M⊙"	2	12	5210.549	[illegible]
Fe	3		4		⊙"		10		5215.352
Fe	3		4		⊙"		10		5217.559
Fe	2		2		⊙"		10		[illegible]
Fe	4		4		⊙"		8		5230.014
Fe	7		8		⊙"		9		5233.124
Fe	3		3		⊙"		10		5242.662
Fe	2		2		⊙"		11		5250.391
Fe	3		3		⊙"		11		5250.825
Fe	2		3		⊙"		12		5253.649
Ca	2		1		M⊙$_1$	1	5	5260.556	5260.557
Ca	6		3		⊙	1	12		5261.880
Cr	2								
?			1	d	M⊙$_1$		1		5262.341
Ca	6		2		⊙	2	5	5262.408	5262.391
Cr †	4	R	3		⊙		3		5264.327
			6		⊙"		2		5264.371
Ca	6		3		M⊙	2	3	5264.408	5264.395
Ca	8		3		⊙	1	2	5265.725	5265.727
			5		⊙		2		5265.789
(Ni?)			2		⊙		1		5265.884
Cr	4	R							
Fe	6		6		⊙"	1	8	5266.733	5266.729
E_2 Fe‡	8		8	d?	⊙"	1	16	5269.714	5269.722
Ca	10		4		M⊙	2	3	5270.445	5270.448
E_1 §				d	⊙"		12		5270.495
Fe	6		4		M⊙		3		5270.533
Fe	3		3		⊙"		6		5273.344
				d	⊙′		5		5273.443
Fe	3		3		⊙"		8		5273.554
?	?		2						
Cr	5		2	t	⊙"		11		5276.205
Co	3		1						
Fe	4		5		⊙"		11		5281.968

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[*] Components about 0.155 apart on photographic plates (J).

[†] Another set of measurements on photographic plates gives the componen
as 0.083 apart.

[‡] Components about 0.088 apart on photographic plate. It is an excee
ingly difficult double and it is possible that this doubleness of E_2 is really a ca
of the reversal of line in the Sun (J).

[§] Components 0.077 apart as determined by another short series (R); 0.1
on photographic plates (J).

[‖] Components of double about 0.075 apart on photographic plates. The fi
side line to red is about 0.110 from the red component of double (J).

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
Inten-sity.	Appear-ance.	Inten-sity.	Appear-ance.		In Arc.	In Sun.		
5		6		⊙″		11		5283.803
2		2		⊙″		12		5288.708
6	R	4		⊙″		12		5296.873
2		3		⊙″		9		5300.918
3		4		⊙″		10		5307.546
		4		⊙		1		5316.790
	d	6	d	⊙		7		5316.870
2		3		⊙		1		5316.950
9		8		⊙″		8		5324.373
3		4		⊙′		9		5333.092
7		5		M⊙	1	4	5349.599	5349.623
75	t?			M	2		5350.670	
3 3		4		⊙1		8		5353.592
		2		⊙		7		5361.813
1 3		1	d	⊙		5		5363.011
?		3		⊙1		1		5363.056
4		6		⊙″		8		5367.670
4		6		⊙″		8		5370.165
2 9 2		2 7	d	⊙1		8		5371.686
2		3		⊙″		9		5379.776
6		6	·	⊙″		11		5383.576
3		4		⊙″		11		5389.683
4		5		⊙″		11		5393.378
7		7		· ⊙″	1	12	5397.319	5397.346
7		7		⊙″	1	14	5405.979	5405.987
10	R	5		⊙″		7		5410.000
4 4		6		⊙″		12		5415.421
3 5		7		⊙″		10		5424.284

distance apart of the components of this 1474 line measured accurately
y Crew, and 0.141 by Rowland. The coincidences with Fe and Co are
tful. The Co line comes more nearly between the two rather than co-
vith either (R).

of substances in the arc gave the following results, iron, manganese,
, titanium and two different specimens of meteoric stones showed two
having the same relative intensities with respect to each other as the
ts of 1474 in the solar spectrum, and either coincided with the compo-
474 or nearly so. When cobalt and nickel were tried, the lines were the
ance apart but the relative intensities were reversed, the red component
h the stronger.

the best definition 1474 is a triple, or rather a double the red compo-
vhich has a weak side line to violet. The components as measured on a
phic plate are respectively 0.120 and 0.050 apart. The main compo-
etermined by a series of measurements on photographic plates are 0.170

bly the violet component is iron and the weak side line of the red com-
cobalt, but the red component is unknown (J).

n but little material in the arc this is a difficult triplet. The violet com-
very strong; the red component about half as strong, and between them
r the red component is a very narrow line much weaker than either of
s (J). ‡ Fine lines near to red.

nponents about 0.110 apart on photographic plates (J).

component itself is an exceedingly difficult double (J).

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Fe	5		6		⊙″	1	9	5434.725	5434.742
Fe*	7		7		⊙″	1	9	5447.116	5447.130
Fe? }			3 }		⊙		1		5455.666
				d	⊙′		8		5455.759
Fe }	6		6 }		⊙		1		5455.826
Ni	3		1		⊙′		7		5462.732
Fe	3		4		⊙″		9		5463.174
Fe	3		4		⊙″		10		5463.493
Fe	3		3		⊙″		10		5466.608
Ni	15	R	4		⊙″		10		5477.128
Fe	2		3		⊙′		5		5487.968
Fe	3		4		⊙″		8		5497.731
Fe	5		4		⊙″		8		5501.685
Fe	5		4		⊙″		8		5507.000
Ca	5	N	3		⊙	1	8	5513.127	5513.207
Mg†	10		7		⊙″	4	8	5528.672	5528.636
Fe			2		⊙″		8		5535.073
Fe	3		2		⊙″		8		5543.418
Fe	3		2		⊙″		9		5544.158
Fe‡	4		3		⊙′		8		5555.113
Fe	6		5		⊙″		8		5569.848
Fe	5		4		⊙″		7		5576.319
Ca	6		4		M⊙″	2	9	5582.204	5582.195
Ca	10	R	6		M⊙″	2	9	5588.977	5588.980
Ca	5		4		M⊙″	2	5	5590.352	5590.342
Ca	7	R	5		M⊙	2	5	5594.689	5594.695
Fe	3		2 }	d	⊙′	1	2	5598.563	5598.555
Ca	7		4 }		⊙′	2	4	5598.712	5598.715
Ca	5		4		M⊙″	2	4	5601.502	5601.501
Fe }	2		2 } }						
Ca }§	6		3 }	t	⊙′		10		5603.097
Fe }	5		5 }						
Fe	2		2		⊙′		10		5615.526
Fe	2		6		⊙′		10		5615.879
Fe‖	2		2		⊙″		12		5624.253
Fe–Va‖	5 2		4		⊙″		14		5624.768
Fe	2		3		⊙″		5		5634.167
Fe	2		3		⊙″		10		5641.661
Si			2		⊙		9		5645.835
Fe	2		4		⊙′		9		5655.707
Yt?	1		4		⊙″		9		5658.096
Fe	3		5		⊙″		9		5662.745
Ti	3		2		⊙		8		5675.648
Fe	2		3		⊙″		8		5679.249
Na	3		4		⊙″		9		5682.861

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* A difficult double (J).

† This Mg line is shaded to one side when there is much Mg in the arc and is therefore a poor metallic standard. The solar line corresponds to the extreme edge of this band-like line (R).

‡ Side line to violet.

§ This triplet is made up of close double and a line close to red stronger than either component of double; wave-length of components about 5602.995; 5603.080 and 5603.180 as measured on a photographic plate (J).

‖ Lines used by Peirce in his determinations of absolute wave-lengths.

s.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
			6		⊙″		7		5688.434
	4		5		⊙″		8		5701.769
			5		⊙″		4		5708.620
			6	d	⊙		6		5709.616
	5		5		⊙		8		5709.760
			6		M⊙	4		5711.374	5711.318
	5 3		5		⊙″		10		5715.309
			5		⊙″		10		5731.973
			3		⊙		10		5742.066
			4		⊙″		10		5752.257
			5		⊙″		10		5753.342
			5		⊙″		9		5754.884
			7		$\odot_1$		8		5763.215
			5		⊙″		6		5772.360
			5		⊙″		9		5775.304
?			7	d?	⊙″		9		5782.346
	6		4		⊙″		9		5784.081
	7		5		⊙″		13		5788.136
	10		7	d?	⊙″		16		5791.207
			4		⊙″		10		5798.087
			5		⊙″		9		5798.400
	7		5		⊙″		8		5805.448
			5		⊙″		7		5806.954
			5		⊙″		14		5809.437
			6		$\odot_1$		14		5816.594
	3		3		⊙′		6		5831.832
	10		5		⊙″		14		5853.903
	10		7		⊙′		14		5857.672
			6		⊙″		15		5859.810
			6		⊙″		16		5862.580
									5875.982
			6 4	d	$\odot_1$		11		5884.048
			3		$\odot_1$		8		5889.854
			15		⊙′		20		5890.182
	3	d?	4		⊙		14		5893.098

s Mg line is shaded on one side, especially when there is much Mg in the
hus should not be used for a metallic standard (R).
ere is a fine line near to violet.
e close to violet.
ere is a Ni line near to red.
s value of the *w-l* of D_3 is the result of three series of measurements
h a grating having 20000 lines to the inch, and is accurate to perhaps

vations were made in the 1st. spectrum on both sides of the Sun. The
not occur as a dark line in the solar spectrum; but is sometimes, if not
present as a very weak bright line. This is shown by a study of the best
phs of this region of the solar spectrum. (J).
ater-vapor line is toward the red about 0.080 from the Fe line and or-
orms a double with it.
exceedingly close equal double when there is very good definition. There
solar line near to the violet and a water-vapor line near to the red.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
D₁Na			10		⊙″		20		5896.154
A(wv) Fe?			3 1	d?	$\odot_1$		10		5898.395
A(wv) Fe?			5 1	d	$\odot_1$		13		5901.681
Fe			5		⊙″		15		5905.895
Fe * ?-(wv)			4 5	d	⊙″		17		5914.384
Fe			5		⊙″		16		5916.475
A(wv)			6		⊙″		12		5919.855
Fe			6		⊙″		14		5930.410
Fe			6		⊙″		13		5934.883
Si			6		⊙″		14		5948.761
Fe			5		⊙″		12		5956.925
Fe			4		⊙″		12		5975.576
Fe			5		⊙		13		5977.005
A(wv)			2		$\odot_1$		1		5977.254
Fe			6		⊙″		6		5985.044
Fe			6		⊙″		7		5987.286
Fe			6		⊙″		7		6003.245
Fe			4		⊙″		3		6008.196
Fe			6		⊙″		6		6008.782
Mn	10		6		⊙″		5		6013.717
Mn	10		6		⊙″		8		6016.856
? † Fe			3 5	d	$\odot_1$		6		6020.347
Mn	10		5		⊙″		6		6022.017
Fe			6		⊙″		8		6024.280
Fe			4		⊙″		7		6027.265
Fe			4		⊙″		8		6042.316
Fe			5		⊙″		9		6056.232
Fe			7		⊙″		13		6065.708
Fe			5		⊙″		13		6078.709
Fe			3		⊙″		12		6079.223
Fe			4		⊙′		4		6102.408
Ca ‡	10	R	6		⊙″		9		6102.941
Fe ?			4 1	d	$\odot_1$		8		6103.449
Li	20				M	4		6103.812	
Ni	5		6		⊙″		8		6108.338
Ni	4		3		⊙′		8		6111.287
Fe	5		6		⊙″		8		6116.415
Ca	15	R	9		⊙″		11		6122.428
Fe			8		⊙′		9		6136.834
Fe–Ba	?-15		7		⊙″		9		6141.934
Na			3		⊙″		5		6154.431
Na			5		⊙″		4		6160.970
Ca	15	R	10		⊙″		9		6162.383
Ca	6		6		⊙″		4		6169.260
Ca	7		7		⊙″		8		6169.775

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* Components about 0.100 apart. Red component is partly solar and partly water-vapor. (J).

† Components about 0.200 apart.

‡ Components 0.100 apart.

	In Arc.		In Sun.			Weight.			
s.	Inten-sity.	Appear-ance.	Inten-sity.	Appear-ance.	Kind of Standard.	In Arc.	In Sun.	Wave-length in Arc.	Wave-length in Sun.
			6		⊙″		8		6173.554
	5		6		⊙″		8		6177.028
			6		⊙″		8		6180.419
	4		6		⊙″		9		6191.397
			8		⊙″		10		6191.770
			6		⊙″		10		6200.533
			6		⊙″		9		6213.646
			6		⊙″		10		6219.493
	?-6		7		⊙″		12		6230.946
			4		⊙″		8		6237.529
			7		⊙″		9		6246.530
			7		⊙″		9		6252.776
			7		⊙″		9		6254.454
	7 ?		6		⊙″		8		6256.574
	5		2		⊙″		9		6261.316
			5		⊙″		11		6265.347
			3		⊙″		10		6270.439
			4	d	⊙″		9		6278.289
			2		⊙′		7		6281.374
			2		⊙′		5		6289.608
			3		⊙		6		6293.152
			3		⊙″		7		6296.144
			7		⊙″		7		6301.719
	6		4		⊙″		7		6314.874
			3		$\odot_1$		5		6315.541
)			6		⊙″		14		6318.242
			5		⊙″		13		6322.912
			6		⊙″		12		6335.550
			6		⊙″		12		6337.042
			5		⊙″		6		6344.370
			5		⊙		8		6355.259
			6		⊙″		8		6358.902
	5		2		$\odot_1$		2		6378.461
			4		⊙″		6		6380.951
			7		⊙″		9		6393.818
			8⎱		$\odot_1$		5		6400.200
			3⎰		$\odot_1$		6		6400.509
			6		⊙″		8		6408.231
			7		⊙″		10		6411.864
			5		⊙″		8		6420.171
			6		⊙		10		6421.569
			6		⊙″		10		6431.063
					M	1		6438.680	
	10	R	7		⊙″		11		6439.298
	5		6		⊙″		6		6450.029

is is a difficult double or there is a side line close to violet.
ief line in the α group. It is a very close atmospheric double with some
nospheric lines to red and a faint water-vapor line near to violet (J).
st line of the first pair of lines in the tail of the α group.
ond line in the second pair of the tail of α. Faint line to violet.
le line to red.
int line near to red.
ere is a Ni line to red.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
Ca Fe	10 ?	R	9 3	d	⊙″		9		6462.835
Ca	5		5		⊙″		7		6471.881
A(wv)			1		⊙		6		6480.264
?			4		⊙″		8		6482.099
Ca	8		6		⊙″		10		6494.001
Fe			7		⊙″		9		6495.209
Ca	5		5		⊙″		10		6499.871
?	6		4		⊙		7		6516.315
Fe			4		⊙′		10		6518.594
A(wv)			1		⊙		7		6532.546
?			3		⊙″		12		6534.173
Ti Fe	3 ?		6		⊙″		11		6546.486
A(wv)			2		⊙		6		6552.840
C H			30		⊙″		13		6563.054
Fe			6		⊙″		13		6569.461
A(wv)			1		⊙		6		6572.312
?			2		⊙		5		6574.477
Fe*			4		⊙1		7		6575.179
Fe			5		⊙″		11		6593.161
Fe			4		⊙″		12		6594.115
Fe			4		⊙″		9		6609.354
Fe†			3		⊙		7		6633.992
Ni	5		5		⊙″		10		6643.882
?			1	d	⊙″		4		6663.525
Fe			4		⊙″		6		6663.696
Fe			5		⊙″		10		6678.232
?			2		⊙		10		6703.813
?			3		⊙		12		6705.353
Li‡	75	t?			M	3		6708.070	
Ca§	10		5		⊙		10		6717.934
?			3		⊙		10		6722.095
Fe			3		⊙		7		6726.923
Fe			4		⊙″		12		6750.412
Fe			2		⊙′		7		6752.962
Ni	5		4		⊙″		9		6768.044
Ni	2		3		⊙′		10		6772.565
Fe			1		⊙		5		6787.137
Fe			2		⊙′		6		6807.100
Fe			3		⊙″		8		6810.519
Fe			2		⊙′		5		6820.614
Fe			2		⊙′		7		6828.850
Fe			3		⊙′		6		6841.591
Fe			3		⊙′		5		6843.908
Fe			3		⊙′		10		6855.425
A[O]‖			3		⊙′		11		6867.461

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* There is a water-vapor line near to violet.

† There is a faint line near to each side.

‡ With but little material in the arc this is a difficult triplet. The violet component is very strong, the red component about half as strong, and between them but nearer the red component is a very narrow line much weaker than either of the others (J).

§ Side line to violet.

‖ This line and the following one are at the beginning of the head of B. There is a fine line midway between them.

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-length in Sun.
sity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
		3		⊙′		11		6867.800
		1		⊙1		2		6868.124
		6	d	⊙		2		6868.393
		1 3	d	⊙1		3		6868.779
		4	d	⊙′		5		6869.141
		4		⊙′		5		6869.347
		4 4	d	⊙″		12		6870.186
		5		⊙′		6		6871.179
		5		⊙′		6		6871.527
		5		⊙″		5		6872.493
		5		⊙″		4		6873.076
		5		⊙″		5		6874.039
		5		⊙″		5		6874.884
		5		⊙″		9		6875.826
		5		⊙″		7		6876.957
		5		⊙″		7		6877.878
		5		⊙″		11		6879.294
		3		⊙″		11		6880.176
1		1		⊙		5		6881.970
2		1		⊙		5		6882.772
3		1		⊙		5		6883.318
		4		⊙″		13		6884.083
		5		⊙″		12		6886.008
		5		⊙″		12		6886.987
		5		⊙″		5		6889.194
		5		⊙″		5		6890.149
		6		⊙″		5		6892.614
		6		⊙″		5		6893.559
		6		⊙″		7		6896.292
		6		⊙″		8		6897.195
		6		⊙″		6		6900.199
		6		⊙″		8		6901.113
		6		⊙″		5		6904.358
		6		⊙″		5		6905.263
		6		⊙″		5		6908.785
		6		⊙″		9		6909.675
		5		⊙″		5		6913.454
		5		⊙″		4		6914.328
5		3		⊙′		4		6914.819
		2		⊙′		5		6916.957
		4		⊙″		5		6918.363
		4		⊙″		9		6919.245
		3		⊙″		8		6923.557
		3		⊙″		11		6924.420
		2		⊙′		5		6928.992
		2		⊙′		8		6929.838
		1		⊙		4		6934.646
		1		⊙		5		6935.530

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e and the preceding one are at the beginning of the head of B. There
nid way between them.

ncipal line in the head of B. It is a difficult double.

ine at the beginning of the tail of B.

Elements.	In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave-leng in Sun.
	Intensity.	Appearance.	Intensity.	Appearance.		In Arc.	In Sun.		
A(wv?)			8		$\odot''$		10		6947.78
A(wv?)			2	d	$\odot_1$		4		6953.83
A ?			1						
A(wv)			8		$\odot''$		12		6956.70
A(wv?)			3		$\odot$		10		6959.70
A(wv?)			6		$\odot$		12		6961.51
?			2				5		6978.65
A(wv)			5		$\odot'$		10		6986.83
A(wv?)*			5		$\odot$		7		6989.24
A(wv?)†			5	d?	$\odot_1$		6		6999.17
?			4		$\odot$		3		7000.14
?			5		$\odot_1$		5		7006.16
?			3		$\odot$		6		7011.58
A(wv?)			3		$\odot_1$		5		7016.27
A(wv?)			6		$\odot_1$		9		7016.69
?			4		$\odot_1$		1		7023.22
?			3		$\odot_1$		7		7023.74
?			3	d?	$\odot_1$		2		7024.98
?			1				1		7027.19
?			3				7		7027.72
?			6		$\odot'$		8		7035.15
?			2				6		7038.47
?			4		$\odot$		10		7040.05
?			4		$\odot'$		5		7090.64
?			6		$\odot'$		5		7122.49
?			1				4		7147.94
?			7		$\odot'$		4		7148.42
?			3				5		7168.19
A(wv)?			3				6		7176.34
A(wv?)			4				7		7184.78
A(wv?)			5	d			6		7186.55
A(wv)			7				3		7193.92
A(wv)			10		$\odot$		5		7200.75
A(wv)			10		$\odot$.		5		7201.46
A(wv?)			6				4		7216.81
?			8		$\odot$		5		7223.93
?			6				4		7227.76
?			3				3		7232.50
?			8		$\odot$		4		7233.17
A(wv)			4				5		7240.97
A(wv)			15		$\odot$		4		7243.90
A(wv)?			4				2		7247.46
A(wv)?			8				3		7264.85
A(wv)?			8				3		7265.83
?			3	d			2		7270.20
A(wv)?			8				4		7273.25
A(wv)?			6				3		7287.68
A(wv)?			10	d?			3		7290.71
A(wv)			4				3		7300.05
A(wv)?			7				4		7304.47
A(wv)?			5	d?			4		7318.81
?			2				3		7321.05

* There is a line towards the violet.
† There is a line close to violet.

In Arc.		In Sun.		Kind of Standard.	Weight.		Wave-length in Arc.	Wave length in Sun.
nten-sity.	Appear-ance.	Inten-sity.	Appear-ance.		In Arc.	In Sun.		
		2				3		7331.206
		7				2		7389.696
		6				2		7409.554
		6				3		7446.038
		6				2		7462.609
		6				3		7495.351
		6				3		7511.286
		3				1		7545.921
						4		7594.059
		10		⊙′		5		7621.277
		12		⊙		4		7623.526
		12		⊙		4		7624.853
		14		⊙		3		7627.232
		14		⊙		3		7628.585
		14		⊙		3		7659.658
		14		⊙		3		7660.778
		8				3		7665.265
		8				3		7666.239
		7				3		7670.993
		7				3		7671.994
		7				1		7699.374
		4				1		7714.686

ing of the head of A. Outside edge.

ine at the beginning of the tail of A.

(wv) denotes a line due to absorption by the water vapor in the osphere; A(O), a line due to the oxygen in the atmosphere.

IOTE ON THE SPECTROSCOPY OF SULPHUR.*

B. HASSELBERG.

anuary number of this journal Mr. Ames gives under On the probable spectrum of Sulphur," the description tra-violet series of spectral lines, which he has observed tubes filled with hydrogen, and whose peculiar charac- quite certain that they could have no connection with um of this gas. The lines in question formed groups structure to the B group of the solar spectrum, in some apping one another. It seems, then, that in a spectro- small dispersive power these groups would have pre- mselves as flutings of the usual description, with intensity towards the red, because the head of each situated towards the shorter wave-lengths. On ac-

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nicated by the author.

count of the special experimental disposition used for the pu cation of the hydrogen, in which sulphur was employed stop the mercury vapor, Mr. Ames thinks that the mentio series of lines or flutings is probably to be considered as spectrum of sulphur. This surmise may indeed be agreed to, cause the low temperature spectrum of this metalloid cons in the visual part, as is well known, of precisely such fluti whose strong edges are turned towards the violet with decr ing intensity in the opposite direction. The observed gro would then form the hitherto unknown ultra-violet continua of this spectrum. There only remains to be explained the cur circumstance that the groups in question showed themselves in one series of observations, but could not subsequently be re duced in any way whatever. This induces me to call atten to an investigation on the spectrum of hydrogen, in which I served the high temperature spectrum of sulphur in a vac tube under conditions which seem to point to a possible origi the sulphur spectrum in the present case other than the sulp employed in purifying the gas.

In the year 1868 Wüllner* published a paper on the spectr the gases in which he describes a new and peculiar spectrum served by him in highly evacuated hydrogen tubes. Owing to unsatisfactory comparison with other spectra then known W ner was misled to consider this new spectrum as a second spectrum of hydrogen, although its close agreement with line spectrum of sulphur as observed by Plücker was sho afterwards pointed out by Angström,† and in the researches the spectroscopy of hydrogen by Salet no such spectrum found. From these circumstances it then seemed almost cert to every spectroscopist but Wüllner, that the new spectr could have no connection with hydrogen, but must proba be due, either to a contamination of the gas by the sulph acid employed to dry it, or to some other cause. That the lat was in all probability the case is proved by a series of exp ments executed by me in 1880‡, in which the same spectrum obtained in highly evacuated tubes filled with common By these experiments it was demonstrated beyond every do (1) that the spectrum was due to sulphur, and (2) that the phur originated in the vaporization of the glass under the he ing power of the very strong condensed induction sparks

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* Pogg Ann. Bd. CXXXV. p. 497.

† C. R. Vol. LXXIII, p. 368.

‡ Bulletin de l'Académie de St. Petersbourg, T. XXVII, p. 97.

'he first conclusion was arrived at by the close agree-
e wave-lengths and intensities of about 40 lines in the
rum with the measurements of the high temperature
of sulphur by Plücker after reduction to wave-lengths,
:tness of the second inference followed from the fact,
pectrum could be obtained only in one specimen of cap-
s-tube, but not in others tried under precisely the same
:al conditions. In this way not only the alleged
e spectrum of hydrogen was definitely abolished but
nilar line spectrum of oxygen, which Wüllner had at-
o this gas, was found to be nothing else than the spec-
hlorine vaporized from the glass by the heat of the
charges.
e above it seems to me that the spectrum observed by
if indeed a part of the low temperature spectrum of
as most probably due to the vaporization of the special
employed, in which case the impossibility of obtain-
ther tubes of different composition is satisfactorily ex-
n order to test this supposition more closely the first
e done is obviously an exact investigation on the fluted
of sulphur. Of this spectrum very little is as yet known,
earches of Plücker, Hittorf and Salet are indeed so im-
t from them nothing but the existence of it can be con-
his is for the visual part, whereas the ultra-violet
completely unknown. Should a comparison of Mr.
trum with the sulphur spectrum thus examined prove
ity, then the exceptional appearance of it in only one
think, be explained on the same ground as the presence
spectrum in the hydrogen tubes of Wüllner.
)LM, Feb. 10th, 1893.

OTE ON THE SPECTRUM OF NOVA AURIGÆ.*

WILLIAM HUGGINS.

erhaps be desirable on account of the near positions of
bands in the spectrum of Nova Aurigæ to those of the
es, to anticipate the account of our observations of the
ctrum of this star so far as to state at once the results
ination of the character of the brightest band, on the
'eb. 7th, 8th and 10th.

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nicated by the author.

When the band was observed in the spectrum of the sec order of a 4-inch Rowland grating, 14438 lines to the inch, v a magnifying power of 23 diameters, it was resolved into a l group of lines extending through about 15 tenth-meters. lines appeared more or less bright upon a faintly luminous b ground which could be traced a little beyond the lines at b ends of the group. Two lines, the brightest in the group about equally bright, formed the termination of the gr towards the blue; and a line nearly as bright as these was about the middle of the group.

The group is therefore brighter at the blue end, but it does possess any of the features of a fluting.

No contrast in the spectroscope could well be more stril than that which this extended group of lines forms with the row and defined principal line in the nebula of Orion.

UPPER TULSE HILL, London.
Feb. 11th, 1893.

VISUAL OBSERVATIONS OF THE SPECTRUM OF β LYRÆ.[*]

JAMES E. KEELER.

The variable star β Lyræ has been an object of extreme inte to students of stellar spectroscopy ever since the discovery bright lines in its spectrum by Secchi, but until recently no ob vations have been made with telescopes of adequate size. W I began spectroscopic work at the Lick Observatory in 18 with the advantage of the great light-gathering power of thirty-six-inch refractor, this star was naturally one of the f that engaged my attention, and I observed it frequently in course of other work. The object of the observations was connect possible changes in the spectrum of the star with period of light-variability. Previous attempts in this direct had brought out little more than the fact that such a connect probably exists, but I hoped for a greater measure of success, account of the more powerful means at my command and uniformity of atmospheric conditions at Mt. Hamilton dur the summer months. After a large number of observations l been made, without reference to the star's period, they w platted on the light curve of the star. The recorded appearan of the spectrum were in some degree contradictory. Cert

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[*] Communicated by the author.

s were indeed obtained, but I was unable to give a xplanation of them, and awaited a longer series of which was left incomplete when I withdrew from ry. These observations have never been published, likely that they will be continued, as it has been isual observations cannot in general compete with methods applied to the same or even to a much ope. They have, however, some features of interest, late chiefly to a part of the spectrum that can ographed readily and hence they may supplement in arriving at a complete explanation of the com- ena presented by this star. The remarkable re- d with the aid of photography by Pickering* and by Belopolsky†, leave little doubt that such an ex- ll soon be forthcoming. I have therefore, with Pro- n's permission, made an abstract of these observa- purpose of the present article.

arks on the instruments and methods are necessary. scope commonly employed was a small instrument the Chabot Observatory. The collimator and ob- cope of this spectroscope have each a focal length of The observing telescope is fixed in a position corre- a deviation of about 50°, which is greater than the eviation of any part of the visible spectrum, and n is brought into the field by rotating the prism. In vations the prism was used in the position which gave spersion, *i. e.*, with the refracting edge turned toward ng telescope. No measurements can be made with this , and the positions of lines which are given in some of tions were determined with the large spectroscope de- he February (1892) number of this journal. It was the relative visibility of lines in different parts of the epended greatly upon the arrangement of apparatus a fact which will be readily understood on considering atic aberration of the great telescope. The color curve ly above F, and the width of the spectrum at this s in a corresponding manner. An abnormal distribu- t is thus produced which interferes greatly with the ob- of a faint line. Applying greater dispersion would ten this difficulty, and hence might make a line in the blue picuous, while a line in the yellow, where the sides of um are nearly parallel, might become fainter, especially

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051. † *A. N.* 3129.

if it were broad and diffuse. Hence the necessity of always usi the same instrument for purposes of comparison.

In the observations which follow, the spectrum is frequent described as having the "usual appearance," and it is necessa to define what is meant by this term. With the small spectr scope above mentioned, the continuous spectrum of β Lyræ w beautifully bright, showing vivid colors.*. It extended fro about C to above F, where, with the usual adjustment in the cal plane of the great telescope, it spread out into a broad fa shaped sheaf of light, and was lost. The C and F lines we bright and easily visible, particularly C, and broader than t same lines in γ Cassiopeiæ. The most conspicuous line in t spectrum was D_3, a very bright and broad line. Just below the dark D line was always seen, as a strong dark shade, blurred that the component lines could seldom be distinguishe Next to the lines above mentioned the most conspicuous brig line was a faint bright line in the greenish yellow at about λ 56 Below F was a rather faint greenish-blue line at about λ 502.

The variations in the brightness of these lines were found to most perceptible in the case of the two last mentioned, probab because they were nearer the limit of visibility than the othe and anything unusual in their appearance was therefore careful noted. For purposes of reference I have called these two lines and *f* respectively.

For the convenience of the reader I have given the positi which each observation occupies when platted on the light-cur of the star, but it will be remembered that the platting was subsequent process, and that all the estimates of the appearan of the spectrum were unbiased by any previous knowledge the phase of the star at the time of observation.

OBSERVATIONS.

1889, June 6 and June 7. The positions of the hydrogen lin and D_3 line were measured with the large spectroscope and 6 prism and the lines identified. The dark shade at D was es mated to begin one width of the broad D_3 line below the less frangible edge of the latter.

June 13. One day past principal minimum. C bright, F rath dim, *d* is distinct, but not very bright. D broad and black; cou not be seen double. There appeared to be a fine bright line clo to D_3 on the more refrangible side, independently noticed by Pr fessor Holden (see figure, No. 2).

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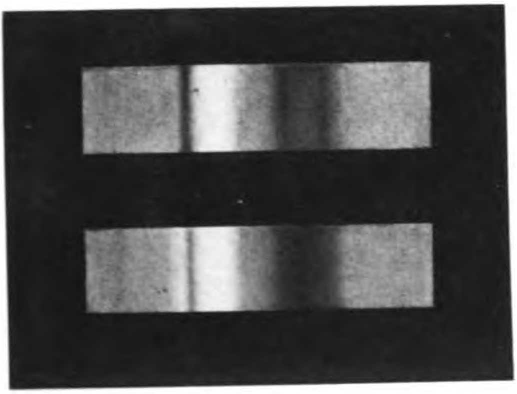
* The bright C and F lines are easily seen in the spectrum of Pleione, b there is no line visible at the place of D_3.

PLATE XXII.



The D_3 Line in the Spectrum of β Lyræ.

1. Nov. 14 and 15, 1889.
2. June 13, 1889.

14. Two days past principal minimum. D_3 very bright,
, C quite bright, F perhaps fainter than usual, *d* well seen.
ectrum is probably full of bright lines, which would be
en if there were more light. Suspected dark band below C
oubtful).

15. First maximum. Spectrum brilliant. C and F much
er than usual, D_3 very bright, but I cannot say whether it
hter than usual. The continuous spectrum extends a con-
le distance below C. D dark, about as usual. At times I
can see a fine bright line in or just below it. This may be
contrast, or possibly it is a reversal of the line. *d* is easily
that the focus can be adjusted by it. Other bright lines
73 and λ 551 (estimated positions), and some others still
. A dark band was suspected below C (very doubtful.)

16. One day past first maximum. Spectrum same as
ght.

18. Secondary minimum. Spectrum about as usual.
gen lines bright. The bright line called *f* seen for the first
With this spectroscope it is as far below F as *d* is above

20. One and one-half day before second maximum. The
n of *d* was measured with the large spectroscope and 30°
The distance between D_3 and *d* was measured with the
neter and with the circle, and was found to be 3′ 4″, mak-
wave-length of $d = 5670$.

distance between the D_3 line and the estimated center of
k shade D was measured with the micrometer, and found
8″. The true interval between D and D_3, from the curve
30° prism, is 15″.

21. One-half day before second maximum. Spectrum
hydrogen lines also bright, particularly C. D_3 and D as
f seen without much difficulty.

22. One-half day past second maximum. Spectrum
as usual,—perhaps the hydrogen lines are somewhat
r than the average. *d* and *f* seen. Dark bands some-
between F and *f* almost certain.

28. First maximum. Spectrum bright, but blurring badly.
drogen lines appeared to be somewhat brighter than usual
ine perhaps darker, *d* quite bright.

29. One day past first maximum. Spectrum same as last
Seeing bad.

2. Secondary maximum. One observation with the same
oscope on the 12-inch equatorial. D_3 seen easily and the
gen lines with difficulty.

July 4. One-half day before second maximum. Spectrum as usual.

July 5. One-half day after second maximum. Spectrum bright and as usual.

July 11. First maximum. Spectrum bright, and as usual. D brilliant, *d* easily seen, *f* seen with difficulty. No new lines.

July 12. One day past first maximum. Spectrum about as usual, perhaps brighter than the average.

July 18. One day past second maximum. About the same as usual; lines quite bright.

July 19. One half day before principal minimum. Spectrum dimmer than usual; D_3 was dimmer, and D darker; C easily seen, F a little difficult. Saw *f*, but thought there were dark absorbtion lines near it.

July 25. One-half day past first maximum. Spectrum bright, and the lines seemed to be unusually brilliant. *d* very distinct. D was distinct, but apparently not quite so dark as usual. The seeing was bad, and the lines were very much blurred.

July 26. One day before secondary minimum. Spectrum about as usual.

Aug. 1. One day before principal minimum. Spectrum nearly as usual. D_3 rather dim, and D unusually dark.

Aug. 2. One-half day past principal minimum. The spectrum has an unusual appearance to-night. The seeing is good. The D_3 line appears particularly sharp and bright, and the D line unusually dark. The hydrogen lines are bright, and F is remarkably conspicuous. Just below F, between that line and *f*, is a black line,* quite easy to see. *f* (bright) seen occasionally. Other absorption bands seen indistinctly in this vicinity. *d* absolutely invisible.

Aug. 9. Secondary minimum. Spectrum about as usual, except that *f* is uncommonly bright and distinct, being nearly equal to *d*, which is seen easily. Below *f* and close to it, appears to be a faint dark line or band.

Aug. 16. One-half day past principal minimum. D_3 line sharp and bright, D darker than usual, F rather bright. Black line noted on Aug. 2 was seen again. *d* not seen; perhaps it becomes invisible at the same time that the black line appears.

Aug. 21. One day before secondary minimum. The hydrogen lines do not seem quite so bright as usual. D_3 about the same, but D is not so dark. *d* is quite bright, and *f* is seen without difficulty. Other bright lines also seen. No dark lines below F.

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* Subsequently found to be at λ 492; called *g*.

22. Secondary minimum. About the same as last night,
aps brighter, *f* fairly well seen. No dark lines below F.

29. One-half day past principal minimum. Unusual ap-
ice of spectrum. D_3 is dim, but sharper than usual, D dark
rong. Black line below F (*g*, at λ 492) easily seen. *d* and *f*
ile.

30. One and one-half day past principal minimum. Spec-
seems bright, but the bright lines are dim. D_3 dimmer
have yet seen it, sharp and narrow. F seen with difficulty,
lack line (*g*) seen, but it is not so strong as it was last
C quite dim, *f* not seen, *d* just visible.

5. One day past secondary minimum. Hydrogen lines
right, *d* seen easily. It is nearly as bright as I have seen
out as broad as D_3 but very much fainter. *f* seen with diffi-
D_3 bright and broad, D not very dark. No black lines
F.

6. One day before second maximum. Spectrum about as
d easily visible, *f* seen with difficulty. No absorption
blue or green. The D line of average depth. Comparison
spirit lamp showed that it was apparently coincident
he double line of sodium.

12. Two days past principal minimum. Spectrum
but lines rather dim. F rather difficult; at times sus-
a dark line close to it, and just above. D_3 somewhat dim,
arp. *d* is easy, D strong and dark, *f* not seen. C is com-
vely brighter than F.

14. One-half day past first maximum. About as usual.

19. One day before second maximum. About as usual.
er faint, *d* bright, *f* easy.

27. One-half day past first maximum. About as usual,
y bright and D rather faint. *d* and *f* seen. Sky hazy, but
im pretty bright.

28. One and one-half day past first maximum. About
ne as last night.

30. One-half day past secondary minimum. The same
al.

3. Second maximum. Hydrogen lines brighter than
D_3 bright and sharp, D dim, *d* bright and rather broad, f
and easy. Whole spectrum bright.

4. One day past second maximum. Lines bright, but not
o bright as on the 3d. *d* and *f* seen easily.

10. One day past first maximum. Spectrum about as
and bright. D dim, *f* seen, *d* as bright as I have ever seen

Oct. 11. Two days past first maximum. Just about the same as last night.

Nov. 7. One-half day before secondary minimum. With the large spectroscope, determined the position of the bright line *f*, by measuring its distance from the F line with the micrometer. A compound prism giving a dispersion of 9° from B to Hγ was used, set to minimum deviation for F. The measured distance was 14.010 rev. Subsequent measures in the solar spectrum for reduction give for the place of *f*, λ 5015.

With the compound prism, used for the first time on this star, the lines in the upper part of the spectrum were more easily observed than with the small spectroscope.

Nov. 8. One-half day after secondary minimum. Same apparatus as last night. *f* measured again, but roughly, on account of thin clouds. A new bright line was seen between *f* and F. It was subsequently found to be the bright companion line of *g*.

Nov. 9. One and one-half day after secondary minimum. Spectrum bright, *d* and *f* brighter than the average.

Nov. 13. One day before principal minimum. Definition bad, but lines fairly distinct at times. Lines not very bright. *d* and *f* seen.

Nov. 14. Principal minimum. Spectrum dim, and of unusual appearance. The D lines are strong, dark and hazy. The interval between the center of the dark shade and the center of the D_3 line was measured with the large spectroscope and compound prism, and found to be 0.623 rev. of the micrometer = 13.75 tenth-metres. This is less than the distance in the solar spectrum (17.08 tenth-metres).* The different measures are, however, very accordant. According to a single comparison with the sodium lines furnished by a spirit lamp, the D lines of the star were displaced toward the violet by about two tenth-metres. The comparison was only a rough one.

Close to D_3 on its more refrangible side is a fine dark line (see figure, No. 1). Its distance from the center of D_3, as measured with the micrometer, was 0.179 rev. = 3.95 tenth-metres. It is remarkable that this dark line is distant from D by an interval (17.70 tenth-metres) which very nearly represents the normal distance of D_3 from D.

Below F were seen two black lines, each with a bright line adjoining it on its less refrangible edge. The bright lines were somewhat like flutings, being sharply bounded by the dark lines above, and fading off more gradually on the lower side. One of

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* Scheiner's Spectralanalyse der Gestirne, p. 198.

lines was *f*, the other the black line *g* seen on former oc-
s.

sures with the micrometer gave the following results:

Bright line, F		$\lambda = 4861.7$ (Assumed).
1st line, (*g*)	Dark line	4920.8
	Bright line	4925.1
2nd line, (*f*)	Dark line	5013.2
	Bright line	5018.4

. 15. One day past principal minimum. The spectrum is
D_3 has the same appearance as last night. D very dark;
een separately at times. Sharp dark line above D_3, as seen
ght. *d* invisible, F dim. The absorption lines with bright
measured last night are still visible, but now the dark
re very prominent, whereas last night the dark lines were
nspicuous than the bright borders. One new line (*e*) of the
kind was seen below *f*.

positions of the dark lines were determined with the mi-
ter.

Bright line, (F)	$\lambda = 4861.7$ (Assumed)
First dark line below, (*g*)	4917.3
Second dark line below, (*f*)	5011.9
Third dark line below, (*e*)	5165 ± (difficult).

bright lines, bordering the above dark lines on their less re-
ble sides, were not measured.

. 21. One day after secondary minimum. Spectrum about
al. *d* and *f* seen. The star is now getting too low for ob-
ion.

). May 8. One day after secondary minimum. Spectrum
as usual.

16. One day before first maximum. Lines rather dim.
lines seen below F. *d* visible; at times I suspected a dark
its less refrangible side.

19. Two days past principal minimum. Spectrum not
ifferent from its usual condition. Hydrogen and D lines
; *d* seen, but it is not very bright. Traces of the dark lines
F.

. 11. One day past first maximum. Spectrum bright, and
ht lines conspicuous.

. 12. One day before secondary minimum. Spectrum just
the same as last night.

large spectroscope noticed that *d* was barely visible with
sm set to minimum deviation, but that it was easily seen
the prism was turned so as to diminish the dispersion.
hows that *d* is a broad line.

1891. May 7. Second maximum. Continuous spectrum and bright lines are bright, D is not very dark, and hazy. *d* visible.

An attempt was made to measure the position of the D_3 line with a diffraction grating on the large spectroscope, but the line was very dim, and too broad and diffuse for measurement.

The observations given above are to seme extent contradictory, but this is by no means surprising, considering the fact that the estimates of brightness were made with no better guide than the remembrance of a previous appearance of the spectrum. Making all due allowance for errors arising from the lack of a suitable standard of reference, I think that a connection between the changes in the spectrum and the light period of the star is fairly established by the observations. The conclusions which it seems to me may be drawn from a consideration of all the observations are as follows:

1. In the spectrum of *β* Lyræ the bright hydrogen lines C and F, the bright D_3 line, and the dark D lines are always visible with a telescope as large as the Lick refractor.* Certain fainter bright lines are visible except at the time of a principal minimum.

2. The variations in the light of the star are principally due to changes in the brightness of the continuous spectrum.

3. The bright lines are brightest when the continuous spectrum is brightest. This is the case in most of the observations. certain exceptions may possibly be real, in which case they would indicate either irregular variations of brightness, or a variation having a period different from that of the star, or they may be due to errors of estimation arising from the diminished brightness of the continuous spectrum at the time of a principal minimum.

4. The bright lines are broad and diffuse, particularly when the star is at a maximum. The D lines are very hazy, so that the components are hardly distinguishable.

5. During the greater part of the period of the star no remarkable changes occur in the appearance of the spectrum. The observations fail to show any connection between changes in the spectrum and the secondary minimum of the star.

6. The most remarkable changes take place at the time of a principal minimum. The bright lines become dimmer, and perhaps sharper. The fainter bright lines disappear. The D lines become darker. Strong absorption lines appear on the more refrangible side of certain bright lines in the green, the separation

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* Strictly speaking, the conclusion is, of course, that these lines were visible during the period covered by the observations. Some remarks on this subject are given further on.

rk and bright lines being at least five tenth-metres.
ght lines are perhaps similarly affected. A narrow dark
ars above the D_3 line at the same time. Shortly before
aximum is reached the dark lines disappear.

nclusions are decidedly at variance with older observa-
I have gone over some of the latter rather carefully,
ly those of Herr von Gothard in *A. N.* 2651, platting
he light-curve of the star in order to see if any corres-
with my own observations could be found, but I must
very unsatisfactory results. Certainly the spectrum of
during the time covered by my observations, exhibited
xtreme and erratic changes as those described by Herr
ard. Without denying the possibility of much greater
han those which I observed, I think that some of the
ariations formerly recorded may be attributed to the
of the instruments employed. In the case of a line
the limit of vision, slight fluctuations in its brightness,
variations of other conditions, would make all the dif-
tween visibility and invisibility. With a larger tele-
n the Lick refractor, I have no doubt that the line I
d *d* would be seen even at the time of a principal mini-
the same time, I am free to confess that this explana-
s to be insufficient. Future observations with large in-
will no doubt decide the matter, as it is highly improb-
irregular variations, if they formerly existed, should
to a sudden end.

now no doubt that the phenomena I observed are only
much more complex series of changes, which could not
tely followed with the method of observation I em-
t appears from the photographic researches of Picker-
f Belopolsky, that the principal dark lines oscillate to
ross the corresponding bright lines, so that the partial
ance of the latter is due to the superposition of the
of lines. On comparing Herr Belopolsky's table of po-
the different components of the F line, in *A. N.* 3129,
light curve of the star, I find that there are only three
ons made near the time of a principal minimum. Of
one, that of Sept. 27, 1892, was made at a phase for
ave corresponding observations (1½ day past the prin-
imum), and the agreement in this case is complete. In
he other cases, which do not fall near the time of a prin-
mum, the dark line is superposed on the bright one, and
would have escaped detection by visual means. On

one or two occasions my notes record the fact that a dark lin was suspected on the less refrangible side of a bright one, but cannot decide from Herr Belopolsky's table whether these observations are in agreement with his own or not. Unfortunately made no observations with the compound prism, (which seeme to give just the right amount of dispersion), just before the tim of a principal minimum.

There is no difficulty in identifying the strong lines which I observed in the green with the strong lines measured by Belopolsk and printed in his table with heavy-faced type. F is the referenc line in both measurements, λ 4922.7 = g, λ 5014.3 = f, λ 5170. = e. There is, however, no line in his table corresponding to d the nearest line there given which seems to answer the description being at λ 5703.3, while my measurements gave for d, λ = 5670. Although these measurements were made with low dispersion, the independent results were in fair agreement, and I do not think the errors of observation were great enough to account for a discrepancy of 67 tenth-metres. The finer lines photographed by Belopolsky were not visible with my apparatus.

The observations which I have recorded of the strong lines seen in the green part of the spectrum after a principal minimum are also in agreement with Professor Pickering's description of the photographed lines above F, both as to the appearance of the bright and dark lines and the direction of the relative displacement.

Some of the phenomena presented by the spectrum of β Lyræ are of particular interest. Is the dark line which appears above D_3 at the time of a principal minimum, when dark lines are seen in corresponding positions near other bright lines, a reversal of D_3? We may safely assume such a relationship in the other cases, but in the case of D_3 so strong an absorption would be quite unprecedented. The line is narrow, while D_3 is broad; but it is remarkable that on Nov. 14, when accurate measures were made, this dark line was more nearly in the normal position of D_3, with reference to the dark D lines, than was the bright D_3 line itself. The latter was relatively displaced toward the red, by an amount nearly equal to the displacement of the other bright lines.

It is also remarkable that the dark and bright lines should exhibit a strong relative displacement at (or at least very shortly after) the time of a principal minimum. Hence a simple eclipse of one body by another would seem to be an insufficient explanation of the diminution of light at this time, whatever constitu-

r be assigned to the two bodies. Evidently more obser-
are needed at this critical period. With the materials at
is futile to attempt a complete explanation of the com-
nomena presented by this star. It seems to me that
Professor Pickering's suggestions are likely to prove suf-
Photography promises to be the method by which the
will be reached, but I have given these visual observa-
the hope that they also will be useful.

egard to the two figures representing the appearance of
ne, I wish to say that although drawn to the same scale,
nals were made under very different conditions. No. 1 is
sketch accompanied by micrometer measures with the
d prism and large spectroscope, No. 2 is from a sketch
th the small spectroscope which was used in most of the
ions, the spacing and widths of the lines being merely
ates.

NOTE ON THE SPECTRUM OF P CYGNI.*

JAMES E. KEELER.

ing over my note-books for observations of β Lyræ, I
following notes in regard to the spectrum of P Cygni.
tain some facts hitherto unpublished.

1, 1889. The spectrum is remarkably like that of β
t the hydrogen lines are sharper and more brilliant, and
Cygni is seen nearly as well as F in β Lyræ. The D_3 line
r and sharper. The dark D line is present, but it is not
conspicuous as in the other star. A sharp fine line is
e estimated position of *f*, but it is much brighter than *f*
e. On the other hand the line above D_3 (*d*), is not cer-
en. Compared with β Lyræ, the continuous spectrum

, 1889. The spectrum is the same as before. D_3 is
nd exceedingly fine and sharp;—much finer than in β
he dark D line is relatively fainter; *f* much brighter,
t equal to *d* in β Lyræ. No line can be seen at the place

ove observations were made with the small spectro-
cribed in the previous article. The star was frequently
with the same instrument, without further results, and

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unicated by the author.

no changes were ever detected. Some measures were made o
the night of Nov. 14, with the large spectroscope and compoun
prism.

Nov. 14, 1889. Two bright lines are seen in the green below
Their positions were measured with the micrometer, with the fo
lowing results:

F	λ 4861.7 (Assumed).
g	4923.6
f	5017.6

These are evidently the same lines as those seen in the spectru
of β Lyræ. Their appearance is also the same; each is border
by a dark line just above. The settings are on the bright lines.

D_3, as seen with this much greater dispersion, is sharper a
narrower than the D_3 line of β Lyræ. The D lines could not
seen, but I thought there was a dark line just above D_3 and equ
to it in width. No other lines were noticed.

These observations are given chiefly on account of the appea
ance of the bright lines in the green, which are described as ha
ing dark borders on their more refrangible edges, like the lines
β Lyræ after a principal minimum. It is not likely that this st
also is a revolving system, and possibly some other explanati
of the appearance is required in both cases. As only one observ
tion of P Cygni was made with suitable apparatus, the appea
ance may have been merely a mistaken impression. Perhaps,
this star, the lines in the green, like those of hydrogen, are supe
posed on broad lines of absorption, the lower parts of which we
less conspicuous than the upper, and for this or some oth
reason were overlooked. The star is beyond the reach of m
present instruments.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjec
properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Ke
wood Observatory of the University of Chicago, Chicago, U. S. A. Authors
papers are requested to refer to last page for information in regard to illustr
tions, reprint copies, etc.

A New Method of Observing the Solar Corona without an Eclipse.—*To the E
tor of Astro-Physics:* DEAR SIR: Your exceedingly interesting article "*On t
Photography of the Solar Corona without an Eclipse*" encourages me in the b
lief that you and the readers of your esteemed journal may perhaps be interest
in a method which I designed for the purpose of observing the distribution of t
intense sources of ultra-violet light over the Sun's disc, and also of observing t
solar corona without an eclipse.

which led me to the design of this method rests on the hypothesis
ermost layers of the solar atmosphere and also the solar corona are
-violet light of very short wave-length,—a characteristic of the lu-
f gases especially when it is produced by electrical discharges. Just
two on this point before I proceed to the description of my method.
stigation "*On Coronoidal Discharges*" (ASTRONOMY AND ASTRO-
ic, 1892) I have referred to the possibility of the coronal streamers
o electrical discharges in the solar atmosphere. I have since ex-
opinion on this point somewhat more strongly in a paper read be-
York Academy of Sciences on December 5th, 1892. In this paper I
scientific value of the hypothesis which ascribes the coronal glow to
ectrical flow in the extremely rarefied gaseous matter of the coronal
oscillatory flow being due to the propagation of electrical waves
to the interplanetary space. The electrical waves again being due
discharges and other kinds of electrical disturbances in the solar at-
d on the solar surface. I have also referred to the possibility of the
being due to a fluorescence of the gases in the coronal regions, this
eing due to the action of ultra-violet light of extremely short wave-
radiates from the uppermost layers of the solar atmosphere, where,
the above hypothesis, electrical discharges of more or less oscilla-
er are going on continually. You can therefore see why I should
nxious to devise some method by means of which I should be able
e ultra-violet light of the solar atmosphere and the solar corona.
method that I thought of was very similar to yours. I discussed it
with Professor Rees of Columbia College, and consulted also our mu-
Dr. Ames of Johns Hopkins, on some points concerning this matter;
od seemed to offer difficulties which appeared to be beyond the skill
xperienced in astronomical and astro-physical work, and I therefore
.

nd method consists in forming an image of the Sun and the sur-
ion of the Sun on a very thin well ground plate of uranium glass or
ransparent fluorescent substance, and observing it by means of a
Fig. 1 gives the front view of the apparatus and fig. 2 gives a ver-
through the axis of the shaft.

l rolled flat thin steel
g. 2), 2 feet in diame-
held in position by
plates *e*, *m*, *n*, and
cted to a shaft AB
n self-oiling bearings
tes having been fixed
ft are to be enclosed
n frame, *gh*, which is
base by bolts, *ik* (fig.
n steel plates are to
circular holes of 1
r arranged as indi-
1, the holes belonging
e being marked by
hose belonging to the
by Roman numbers.

Fig. 1.

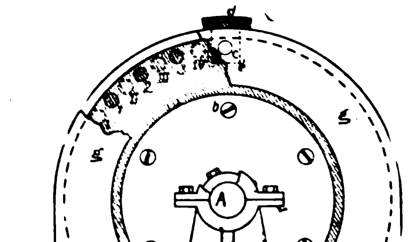
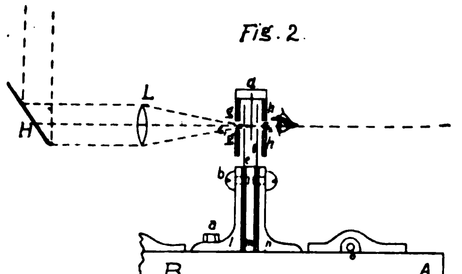


Fig. 2.



Resting on the frame at its highes
point is a block *d* which carries th
fluorescent plate, *df* (fig. 2). Th
frame has two circular holes,
and c_2 (fig. 2), of the same dimer
sions as the holes in the revolvin
steel plates. The uranium plate i
midway between these plates.
heliostat H with a speculum meta
mirror and a quartz lens (or wha
is better still a speculum meta
reflector) are used to form th
image of the Sun or of the regio
surrounding the Sun (in whic
case a reflector or quartz refracto
of short focal length is used) upo
the fluorescent plate. An eye situ
ated as indicated in fig. 2 shoul
see the image by means of th
fluorescent light.

To photograph the image it would probably be desirable to use some othe
substance instead of uranium glass. The angular velocity of the steel discs ca
easily be raised to such a value as to enable the observer to observe the fluore
cent image during every $\frac{1}{2500}$ part of a second after each exposure of the uraniu
plate to the action of the solar light. Each exposure lasts the same fraction
a second.

The diffuse light of the sky would probably be eliminated in this way, e
pecially if transparent fluorescent plates are used which are especially sensitive
ultra-violet light of very short wave-length. Should you think that the metho
deserves any serious consideration, please offer some suggestions which I woul
value very much and observe very carefully in the final design of the apparatus.

Very truly yours, M. I. PUPIN.

Columbia College, March 10th, 1893.

Dr. Pupin's ingenious method of observing the corona without an eclipse is
new way of applying a supposition common to many methods devised for t
same purpose, *i. e.*, that the ultra-violet portion of the corona spectrum
stronger than the less refrangible region. If this supposition be well founded-
and there are many reasons to think that it is—it would seem that D
Pupin's apparatus might succeed in rendering the corona visible to the ey
The experiments would be much more likely to result successfully if tried at a hig
altitude. Instead of a heliostat and quartz lens it would perhaps be advar
tageous to form the image of the Sun with a concave mirror of speculum meta
the whole apparatus being carried on an equatorial mounting. It would als
seem desirable to cut off the direct light of the Sun by means of a metallic disc.

Photography of the Solar Corona without an Eclipse.—In a paper with the abov
title published in the March number of ASTRONOMY AND ASTRO-PHYSICS I hav
described a method of photographing the solar corona without an eclipse, wit
the spectroheliograph. It has occurred to me that the chances of securin
the corona would be greatly increased by setting on the second slit of the spectr
heliograph one of the dark lines in the blue or violet part of the mixed spectru

ona and the sky. The bright continuous spectrum of the corona
f its normal intensity at this point, while the disturbing light of the
e would be reduced to the brightness of the dark line. The K line
ably prove most serviceable. The resulting advantage would be the
afforded by the broad dark absorption band, and the additive effect of
K line in the corona.
16, 1893. GEORGE E. HALE.

rge Prominence of Oct. 3, 1892.—On referring to my notes made on the
I find this prominence was well seen here at from $7^h\ 20^m$ to $8^h\ 50^m$
T., or about 5 hours earlier than the time when it was drawn by Herr
alocsa. When observed by me the prominence consisted of a compact
ery beautiful interlacing filaments extending without a break from
22° to — 39° and about 100″ in height; there was a bright spot or
tion" at — 39° and another at — 43° and outlying prominences were
15° and — 50°. The next morning at the same hour hardly a trace of
ence remained and there is little doubt that it must have been annihi-
g the 24 hours as the Sun's rotation would not carry so large a form
t in this time. Herr Fényi's drawing seems indeed to show the prom-
he act of being blown to shreds.
ther prominences comparable with the above in magnitude have been
uring 1892, both being in S. latitudes. The first on May 14th, $3^h\ 40^m$
ded for no less than 33° on the S.W. limb from latitude — 35° to — 68°,
parts being about 140″ above the limb. The other on July 19th on
nb appeared as a huge column of intertwining filaments, the base being
— 40° and the highest parts nearly 3′ above a point on the limb at
ke the October prominence both these gigantic forms seem to have been
lived. J. EVERSHED, JR.
, Surrey, England.

hmann's Investigations on the Ultra-Violet Spectrum.—In his paper on
rogen line $H\beta$ in the Spectrum of Nova Aurigæ and in the Spectrum of
ubes (ASTRONOMY AND ASTRO-PHYSICS, February, 1893), Herr Schu-
pointed out some remarkable cases of reversals which are worthy of
sideration in the interpretation of celestial phenomena. In a letter of
t date attention is called in the following words to another point of
the same connection: "Among the lines not belonging to, but almost
present in photographs of the hydrogen-tube spectrum in addition to
ercury, the cyanogen band at λ 3883 is especially noticeable. This
naciously resists every attempt to free the spectrum of it. It is only
heating and the passage of strong discharges through the tube that it
weaken in intensity. If, however, this band is taken together with the
of hydrogen one finds that under certain circumstances it is very
nd that it almost entirely disappears under certain experimental
out invariably reappears as soon as the former conditions are restored.
t the cyanogen band always disappears when the temperature of the
is sufficiently increased. If, for instance, only one Leyden jar is used in
ion coil circuit, the band retains its full strength. But, if a second
of sufficient capacity is added, not a trace of the band remains. The
apor from the air-pump acts in nearly the same way."
paper published in our February number and referred to above the
n p. 164 should read: "at a pressure of 32mm. only the two lines $H\beta$
t." The subscripts were omitted in the author's manuscript, and had
lied from the context by the translator.

Differential Gravity Meters.—One by one those old landmarks known a "physical constants" are disappearing. Perhaps the latest step in this directio is the proposal of Mascart [*Comptes Rendus, 30th January, 1893*] to express o familiar "constant" *g* as a function not only of altitude and latitude, but also time. Local variations in the direction of gravity (station errors) have lon been known. At the Princeton Observatory, for instance, the geodetic latitu differs by some four seconds from the accurate determination of the astronomic latitude made by Professor McNeill. Time variations in the direction of gravit were predicted by Lord Kelvin many years ago, and are now being studied wit great zeal.

Added to these we now have the observations of Mascart (*loc. cit.*) whic led him to think that the *intensity* of gravity, at any fixed point on the Earth surface, undergoes rather sudden minute changes.

These indications were obtained from a siphon barometer, the lower tube which was filled with hydrogen and then sealed. Using a mercury column mor than fourteen feet high, he detects any change in the weight of this mass by rea ing the change of level in the lower arm. The cross-sections of the columns ar in the ratio proper to magnify the displacement in the hydrogen tube som twenty times.

Such an arrangement as this is, of course, keenly sensitive to any therma change. To prevent sudden fluctuations it is placed underground.

The noteworthy feature of Mascart's record is that, aside from the slow gentle changes corresponding to the temperature curve of the ground at tha point, he finds sudden twitches or notches in the curve, assignable apparently t sudden changes in the intensity of gravity. These experiments are to be continued at the *Observatoire du Parc Saint-Maur*. The publication of curve showing the character and amount of these changes will be awaited with grea interest.

It will be remembered that the differential gravity meter devised by Lor Kelvin and described by him at the Birmingham meeting of the British Association (1886) was abandoned not only on account of elastic "fatigue" in the flexe spring which he employed, but partly because Mr. Boys, then just out with hi quartz fibres, proposed to use torsion in a horizontally stretched fibre, afte the manner of a catapult whose arm is held back by gravity. It was hoped thu to obtain an instrument which would surpass Lord Kelvin's spring both in delicacy and precision. But if anything farther has come of Mr. Boys' torsio balance, it has escaped your reviewer.

It appears not unlikely that any of these methods possess sufficient delicacy the *bete noire* of the whole problem being those vicious temperature variation which play havoc with so much physical experimentation. Lord Kelvin's spring for instance, would detect a change in *g* as small as one part in two hundre thousand, yielding a clock error of a quarter of a second a day.

Meteorological Balloon.—M. Renard thinks he has obtained a cloth an varnish at once sufficiently light and impervious to hydrogen to make a balloo which will put below itself eleven-twelfths of the Earth's atmosphere, ascendin to a height of 12 miles.

His proposition is to outfit such a balloon with a self-registering baromete thermometer, and actinometer, and then set it free. The instruments are to b packed in a sort of interior skeleton of light willow work. The weight of th whole thing is only twenty pounds, and nearly half this is allotted to the meteorological apparatus. The estimated cost of each ascent is ten dollars. No mention is made of insurance. (*Journal de Physique*, Feb. 1893, pp. 63-67.)

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR MAY.

r will be morning planet during May, rising about three quarters of
ore the Sun during the first half of the month. During the last days
ll be approaching superior conjunction and therefore too near the Sun
tion. On May 20 at 1h 06m P. M., central time, Mercury will be in
with Jupiter. The apparent distance between the two planets will

ill be at superior conjunction on the morning of May 2 and will after
e evening planet setting very soon after the Sun. Toward the last of
one will be able to see the planet with the naked eye, by looking
sunset point between a quarter and a half hour after sunset.

ill be evening planet during May, setting a little after ten o'clock.
will be eastward from the head of Taurus to the feet of Gemini. Mars
conjunction with the Moon, 3° 32′ south of the latter, May 18 at
.

will be in conjunction with the Sun April 27 and will be too near the
ervation during the greater part of May.

will be in excellent position for observation during May, as it will be
idian in the early part of the night. One will find this planet in the
n Virgo a little west of the third magnitude star γ. The planet is
y brighter than any of the neighboring stars.

will be in conjunction with the Moon May 25 at 2h 48m A. M.

will be in its best position for observation for this year during May.
is in the western part of the constellation Libra, about two and one-
s west and one degree north of the bright star α Libræ. It is not
e naked eye but may easily be recognized, by its dull green disk, with
of moderate power. Uranus will be in conjunction with the Moon
5h 44m P. M. As seen from the center of the earth the planet will then
orth of the moon's center. As seen from observations in northern
e parallax will throw the moon farther from the planet.

will be too low in the west in the early evening for observation dur-

MERCURY.

R. A.	Decl.	Rises.	Transits.	Sets.
h m	° ′	h m	h m	h m
1 17.0	+ 4 53	3 59 A. M.	10 22.0 A. M.	4 45 P. M.
2 11.2	+10 37	3 51 "	10 36.7 "	5 21 "
3 21.2	+17 22	3 53 "	11 07.2 "	6 21 "

VENUS.

R. A.	Decl.	Rises.	Transits.	Sets.
2 56.2	+16 05	4 53 A. M.	12 00.8 P. M.	7 09 P. M.
3 45.9	+19 35	4 46 "	12 11.0 "	7 36 "
4 37.4	+22 12	4 46 "	12 23.3 "	8 00 "

MARS.

R. A.	Decl.	Rises.	Transits.	Sets.
5 36.7	+ 24 29	6 52 A. M.	2 41.1 P. M.	10 30 P. M.
6 05.9	+ 24 36	6 40 "	2 29.9 "	10 20 "
6 33.1	+ 24 25	6 30 "	2 18.6 "	10 07 "

JUPITER.

R. A.	Decl.	Rises.	Transits.	Sets.
2 29.7	+13 46	4 37 A. M.	11 36.0 A. M.	6 35 P. M.
2 39.0	+14 31	4 04 "	11 06.0 "	6 08 "
2 48.2	+15 13	3 31 "	10 35.8 "	5 40 "

Date. 1893.	R. A. h m	Decl. ° '	Rises. h m	Transits. h m	Sets. h m
			SATURN.		
May 5	12 29.5	− 0 18	3 31 P. M.	9 32.6 P. M.	3 34 A. M.
15	12 27.8	− 0 09	2 50 "	8 51.6 "	2 53 "
25	12 26.7	− 0 04	2 09 "	8 11.2 "	2 13 "
			URANUS.		
May 5	14 24.7	− 13 52	6 21 P. M.	11 27.4 P. M.	4 34 A. M.
15	14 23.1	− 13 44	5 40 "	10 46.5 "	3 53 "
25	14 21.6	− 13 37	4 58 "	10 05.7 "	3 13 "
			NEPTUNE.		
May 5	4 34.5	+ 20 30	6 10 A. M.	1 39.0 P. M.	9 08 P. M.
15	4 36.0	+ 20 33	5 32 "	1 01.1 "	8 30 "
25	4 37.6	+ 20 36	4 54 "	12 23.4 "	7 53 "
			THE SUN.		
May 5	2 51.8	+ 16 28	4 45 A. M.	11 56.5 A. M.	7 08 P. M.
15	3 30.9	+ 19 03	4 33 "	11 56.2 "	7 19 "
25	4 10.9	+ 21 05	4 24 "	11 56.8 "	7 29 "

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A................$0^h\ 52^m\ 32^s$
Decl.................+81° 17′
Period............2*d* $11^h 50^m$

1893.	
May 3	5 A. M.
8	5 A. M.
13	5 A. M.
18	4 A. M.
23	4 A. M.
28	4 A. M.

S. CANCRI.

R. A...............$8^h\ 37^m\ 39^s$
Decl................+ 19° 26′
Period............9*d* $11^h 38^m$

May 7	1 A. M.
25	1 A. M.

S ANTLIÆ.

R. A................$9^h\ 27^m\ 30^s$
Decl.................—28° 09′
Period............. $7^h\ 47^m$

May 1	11 P. M.
2	11 "
3	10 "
4	10 "
5	9 "
6	8 "

S ANTLIÆ CONT.

7	8 "
8	7 "
12	midn.
13	11 P. M.
14	11 "
15	10 "
16	9 "
17	9 "
18	8 "
19	7 "
24	midn.
25	11 P. M.
26	11 "
27	10 "
28	9 "
29	9 "
30	8 "
31	7 "

δ LIBRÆ.

R. A..............$14^h\ 55^m\ 06^s$
Decl....... ......— 8° 05′
Period........ ..2*d* $7^h\ 51^m$

May 2	midn.
11	11 P. M.
18	11 "
25	11 "

U CORONÆ.

R. A..............$15^h\ 13^m\ 43^s$
Decl...............+ 32° 03′
Period...........2*d* $10^h\ 51^m$

May 11	4 A. M.
18	2 "
24	midn.
27	10 A. M.
30	9 P. M.

U OPHIUCHI.

R. A..............$17^h\ 10^m\ 56^s$
Decl...............+ 1° 20′
Period...... .... 0*d* $20^h\ 8^m$

May 4	3 A. M.
4	11 P. M.
9	4 A. M.
9	midn.
14	4 A. M.
15	1 "
20	1 "
25	2 "
25	10 P. M.
30	3 A. M.
30	11 P. M.

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	Angle f'm N pt. °	EMERSION Washington M. T. h m	Angle f'm N pt. °	Duration. h m
May 3	43 Ophiuchi	5.8	13 33	100	15 07	285	1 34
19	ω^1 Cancri	6.0	7 03	110	8 08	292	1 05
19	ω^2 Cancri	6.3	7 48	161	8 29	241	0 41
24	η Virginis	4.0	9 21	175	10 20	267	0 59

Phases and Aspects of the Moon.

		d	h m	
pogee	May	2	midnight	
ast Quarter	"	8	8 24	P. M.
ew Moon	"	15	4 47	"
erigee	"	16	12 42	A. M.
irst Quarter	"	22	8 52	"
pogee	"	30	1 42	"
ull Moon	"	30	9 12	"

Configuration of Jupiter's Satellites at 8ʰ p. m. Central Time.*

	May		May	
1 ○ 2 3 4	28	3 1 ○ 2 4	31	○ 1 4 2 3
2 3 ○ 4	29	2 ○ 3 1 4		
3 ○ 1 4 ●	30	2 1 ○ 3 4		

e satellites of Jupiter are invisible before May 25th, Jupiter being too Sun.

COMET NOTES.

about time for some new comets to be discovered. The old ones are al-yond the reach of even the great telescopes. Holmes' comet was, on 1, so very faint that it was exceedingly difficult to obtain an accurate ation of its position with the 16-inch equatorial. It was about 1′ in di-ith very slight central condensation.

ks' comet 1893 I has vanished in the rays of the Sun. The following s by F. Ristenpart (*Astr. Nach.* 3154) shows that it may possibly be ked up after it comes out of the solar rays in June or July.

Ephemeris of Comet 1893, I (Brooks 1892, Nov. 19)

	R. A.			Decl.		log r	log Δ	Br.
	h	m	s	°	′			
6	1	08	44	+ 16	51.0	0.2569	0.4447	0.225
2		18	26	15	26.4	2964	4694	167
8		26	58	14	05.3	3333	4830	132
4		32	48	12	42.9	3677	4839	113
9		35	35	11	03.9	3997	4749	101
5		34	23	8	55.8	4293	4580	096
1	1	28	06	+ 6	05.4	0.4569	0.4353	0.093

Elements of Comet 1892 III (Holmes)—Mr. J. R. Hind gives the following in Astr. Nach 3152. They depend on observations Nov. 9, Dec. 7 and

Epoch 1892 Nov. 9.5 Greenwich M. T.

$$M = 21^\circ\,12'\,43''.5$$

$$\left.\begin{array}{l}\pi = 346\ \ 16\ \ 04\ .7\\ \Omega = 331\ \ 35\ \ 38\ .2\\ i = \ \ 20\ \ 46\ \ 46\ .4\end{array}\right\}\ 1892.0$$

Middle Place (C — O)

$\Delta\lambda \cos\beta = -1''.1$; $\Delta\beta = -0''.4$

$$\varphi = \ \ 24\ \ 06\ \ 16\ .1$$

$$\mu = 513''.90765$$

$\log a = 0.5594143$

eriod = 2521.85 days.

elion = 1892 June 13.9062

Ephemeris of Holmes' Comet 1892 III.—Although this comet has again almost vanished from sight we think it well to give the following ephemeris, that observers may keep watch for another possible outburst of light. The ephemeris is by M. Schulhof and is taken from *Astr. Nach.* 3153.

Paris Midn.	R. A.			Decl.			log Δ	Aberr. Time.	
	h	m	s	°	′	″		m	s
April 5	3	31	51.1	+ 36	22	58	0.55255	29	37
6		33	42.0		25	33			
7		35	32.0		28	06			
8		37	24.2		30	38			
9		39	15.5		33	08	55877	30	02
10		41	06.9		35	37			
11		42	58.5		38	04			
12		44	50.2		40	29			
13		46	41.9		42	53	56473	30	27
14		48	33.8		45	14			
15		50	25.8		47	34			
16		52	17.9		49	52			
17		54	10.0		52	09	57044	30	51
18		56	02.3		54	23			
19		57	54.6		56	35			
20	3	59	47.0	36	58	45			
21	4	01	39.4	37	00	52	0.57588	31	15
22		03	31.9		02	58			
23	4	05	24.4	+ 37	05	02			

Suggested Origin of Comet Holmes.—Mr. Corrigan's hypothesis being in the present state of our knowledge not susceptible of proof, yet must be allowed to have a look of probability about it in so far that if such collision betwixt two asteroids took place it might result in analogous phenomena to those we have been observing of late.

But I think the appearance of the comet at the time of discovery and for a few days after was not such as we should expect to result from a collision betwixt two bodies violent enough to cause both to fly into vapor.

When discovered it was accurately round with a bright circular nucleus reminding me much of H37^{4} on a larger scale. It was then 5′ in diameter and it retained this neat, well defined, circular appearance until the 9th of Nov., although it increased in diameter to 5′ 42″.

This neat, sharp, distinct circularity appears to me incompatible with the results of a collision. I should say the material of the two bodies would fly out at right angles to the line of impact and as this line would not be directed in the line of sight we should never see the expanding mass as a circle nor do I see how to account for so distinct an outline.

Again the result of a collision violent enough to produce such an expansion would be considerable heat and light and I am not aware that this comet has ever done more than feebly reflect sunlight without ever emitting the smallest light of its own. Of course the masses of the asteroids being very small they would not collide with the violence of larger masses but if we postulate sufficient force of impact to reduce to fluidity even we ought to get considerable light.

But I think there is the previous question of whether any collision is possible betwixt two bodies of commensurable mass while they are submitted to the controlling influence of the Sun. If they were approaching each other directly, such collision might be possible but if travelling in the same direction round the Sun even in the same orbit, the result of their mutual attractions would be to retard one and accelerate the other; closing in one orbit and widening the other so that they would pass without collision and ever after revolve round their centre of gravity as a double asteroid. If approaching a node common in converging lines they would also be compelled to commence the same on because of their differences of speed producing the same accelerations rdations. Of course these considerations do not apply to bodies of great es of mass or when not subjected to the influence of a third more power- ential mass such as the Sun furnishes, in case of the solar system.

nk we must reject Mr. Corrigan's ingenious hypothesis.

EDWIN HOLMES.

closing letter it struck me that the result of such a collision would be no nucleus at all. If it was heavy enough to drive it into vapor this tion would occur in a very short time and not as in the case of the ccupying a week or more. Perhaps half an hour would suffice to raise masses to the intensest heat.

E. H.

Denning's Drawings of Holmes' Comet.—Mr. W. F. Denning sends the fol- note to accompany the drawings which are reproduced in our Frontis-

sponse to your request for drawings of Holmes' comet, I send 3 pencil tations which will exhibit the marvellous alteration of structure which between November 9 and 19.

ov. 9 I saw the comet as a perfectly round mass of nebulosity with a ntral condensation. The edges of the comet were very definite against sky and in this respect the object might compare with a planetary disc eter was 5′ 40″.

ov. 16 it seemed to have been transformed into an entirely different ob- e diameter had increased to 10′ 33″ and the appearance was that of head devoid of tail. The nucleus was knotted and in the form of a bright material running through the central part of the comet. There nall star just N. of the W. extremity of the nucleus. The comet was nter than on Nov. 9.

ov. 19 a further expansion had occurred and I found the mean diameter ′ 30″. The comet was now a pear-shaped mass of faint nebulosity. It loped a short tail but was much fainter generally than on Nov. 16.

ast time I saw the comet was on Feb. 12, 1893. I also examined it on when the sky was better and found the object still fairly conspicuous. hter portion of the head consisted of knots of nebulosity and the comet sily have been mistaken for a very faint star cluster. A feeble tail was di- om the head towards N. E. and nearly in the direction of the bright star nguli which was in the same field with the comet.

W. F. DENNING.

pston, Bristol, February, 15, 1893.

itive Elements of Comet 1890, III.—In *Astr. Nach.* 3151 is given a de- ion of the elements of this comet from all the available observations. et was observed only from July 19 to Aug. 6 so that the observations only 41. They are represented as closely as could be desired by a .

$$T = 1890 \text{ July } 8.577276 \text{ Berlin M. T.}$$

$$\left.\begin{aligned} \pi &= 99^\circ\ 58'\ 02''.24 \\ \omega &= 85\ \ 39\ \ 36\ .86 \\ \Omega &= 14\ \ 18\ \ 25\ .38 \\ i &= 63\ \ 20\ \ 03\ .70 \end{aligned}\right\} 1890.0$$

$$\log q = 9.8831669$$

Search Ephemeris for Finlay's Periodic Comet, 1886 VII.—The only periodic comet due this year is that discovered by Finlay in 1886, the elements of which bore a close resemblance to those of the lost comet of DeVico. Mr. L. Schulhof has published a search ephemeris, part of which we give below, for it in *Astr. Nach.* 3154. The uncertainty of the perihelion passage is hardly more than ± 2 days. This will correspond on May 1, to an error of ± 5^m in R. A. and ± 30′ in Decl. The comet will not be favorably situated for observation in northern latitudes until the latter part of May, when it may be observed in the morning.

Paris Midn.	R. A.			Decl.		log Δ	Br.
	h	m	s	°	′		
April 6	21	06	36	− 18	42.9	0.2596	0.112
7		09	45	18	30.6		
8		12	55	18	18.0		
9		16	07	18	05.1		
10		19	20	17	51.9	0.2445	0.126
11		22	34	17	38.4		
12		25	49	17	24.5		
13		29	06	17	10.3		
14		32	25	16	55.9	0.2294	0.141
15		35	44	16	41.2		
16		39	05	16	26.1		
17		42	28	16	10.7		
18		45	52	15	54.9	0.2142	0.159
19		49	17	15	38.8		
20		52	44	15	22.4		
21		56	12	15	05.6		
22	21	59	41	14	48.5	0.1992	0.179
23	22	03	12	14	31.0		
24		06	45	14	13.2		
25		10	19	13	55.0		
26		13	55	13	36.5	0.1844	0.202
27		17	32	13	17.6		
28		21	11	12	58.3		
29		24	51	12	38.7		
30		28	33	12	18.7	0.1699	0.227
May 1		32	17	11	58.3		
2		36	02	11	37.6		
3		39	49	11	16.5		
4		43	37	10	55.1	0.1559	0.255
5		47	27	10	33.3		
6		51	19	10	11.1		
7		55	12	9	48.5		
8	22	59	07	9	25.6	0.1424	0.286
9	23	03	04	9	02.3		
10		07	02	8	38.6		
11		11	02	8	14.6		
12		15	03	7	50.3	0.1297	0.319
13		19	06	7	25.6		
14		23	11	7	00.6		
15	23	27	17	− 6	35.3		

New Asteroids.—Three new asteroids have been discovered since our last note The one announced in February as 1893 H turned out to be 1893 G and was on the same plate with (42) Isis.

	Photograph				First Observation		
1893	By	At	Date	Mag.	Gr. M. T.	R. A.	Decl.
					h m	h m s	° ′ ″
F	Wolf	Heidelberg	Jan. 16	13.0	Jan. 16 12 47	9 22 04.2	+ 19 49 46
G	Charlois	Nice	Jan. 21	11.5	Jan. 22 16 13	9 31 33.3	+ 26 13 22
J	Charlois	Nice	Feb. 11	12.5	Feb. 15 6 48	10 19 28	+ 15 02

otal Solar Eclipse, April 15-16, 1893.—By the time the most distant of
rs have received this number of A. AND A.-P., the total eclipse will prob-
been witnessed by the several parties which have gone to South Amer-
frica to observe it. This eclipse being the last in the present century
ikely to add to our knowledge of solar physics, preparations have been
tilize the few precious moments of totality to the best advantage pos
r the circumstances. At least six important expeditions will observe
, two in Chili, two and probably more in Brazil, and two in Africa.

FIG. 1.

ce at the accompanying chart, Fig. 1, will give a general idea of the lo-
the line of central eclipse. The shadow of the moon first touches the
the Southern Pacific Ocean, and passing to the northeast strikes the
Chili, crosses Brazil and the Atlantic Ocean, entering Africa just north of
of the river Gambia, and leaves the Earth in the Sahara. The width
h of the total eclipse is about three times the width of the line drawn
rt.

Fig. 2 shows on a larger scale the points on the African coast from which the total phase of the eclipse may be seen. From *Nature*, Feb. 2, 1893 we learn that an English expedition will be located in Fundium (a station not shown on the map) on the River Salum, 60 miles from Bathurst. This expedition will consist of Professor T. E. Thorpe, Mr. A. Fowler, Mr. Gray, and Sergeant J. Kearney, R. E. They will endeavor to obtain photometric measures of the intensity of the corona with the equatorial photometer, the integrating photometer and bar photometer; spectroscopic observations with the integrating, radial and tangential slit spectroscopes; and photographs of the corona with Abney and Dallmeyer coronographs.

A French expedition under MM. Deslandres and Bigourdan has been sent by the Bureau des Longitudes of Paris to Joal, Africa. M. de la Baume Pluvinel will also go to Joal to photograph the corona.

In Brazil an English expedition under Mr. A. Taylor will be located at Para Curu, on the coast about forty miles west of Ceara. They will obtain photographs of the corona and spectroscopic observations with instruments exactly similar to those used in Africa. In the same vicinity there will also probably be a French party, and a Brazilian party under Mr. Cruls. An expedition from Cordoba, Argentine Republic, under Mr. Thome will probably observe the eclipse near Rosario de la Frontera, Arg. Rep.

In Chili there will be two parties, one from Harvard College Observatory under Mr. Bailey, and one from the Lick Observatory. Just where these parties will be located is not known. Fig. 3 gives a map of the region of totality near the Pacific coast, showing the readily accessible points. We understand that Professor Schaeberle, who goes alone, depending upon finding local assistants, intends to go beyond the terminus of the railroad and find a station among the mining camps in the mountains. He carries with him a 6½-inch equatorial and a 40-foot photoheliograph of 5 inches aperture, and will attempt to photograph the inner and outer corona.

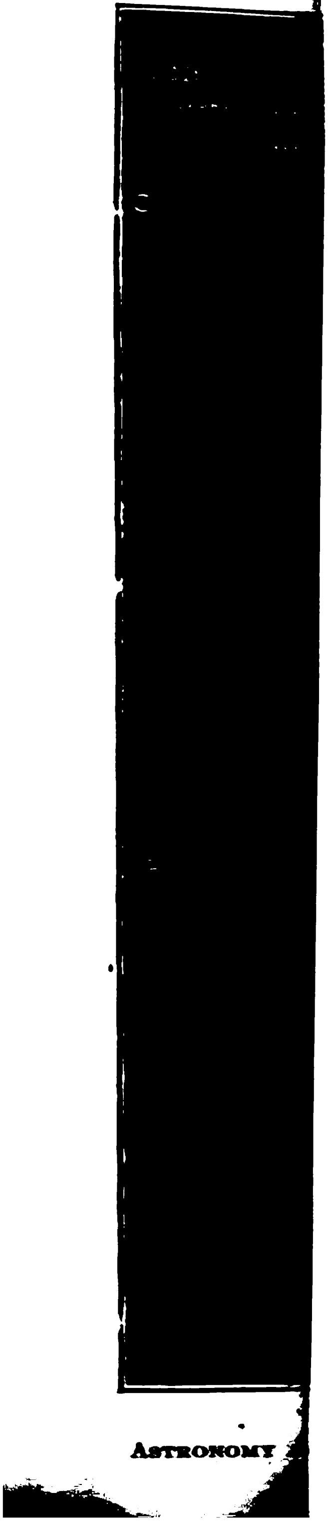
The United States government has made no appropriation for eclipse observations. Mr. D. P. Todd writes that he has had to give up his cherished hope of observing the eclipse. The same is probably true of Mr. H. S. Pritchett, although we have not heard from him directly.

Meteor.—Last evening, at 8.33, a quite bright meteor fell in the N. W. in the constellation of Andromeda. The general direction was S. E. passing near γ Andromedæ. It was accompanied by a bright train, although both path and train were not long. EARNEST BUTTRICK.

100 Wilder St., Lowell, Mass., March 13, 1893.

"Shaking the Foundations of Science."—In an editorial under this title, *Nature* (Jan. 5, 1893), enters a vigorous protest against the proposed construction of an underground railway close to the College of Science buildings at South Kensington. With trains running at short intervals on such a railway, accurate measurements of any kind would be quite impossible. A similar project was entertained two years ago, but it was finally abandoned. The danger is one to which institutions in great cities are always exposed. In this case we hope that the interests of the college will be respected, or that some other route for the railway will be found to offer superior advantages.

375



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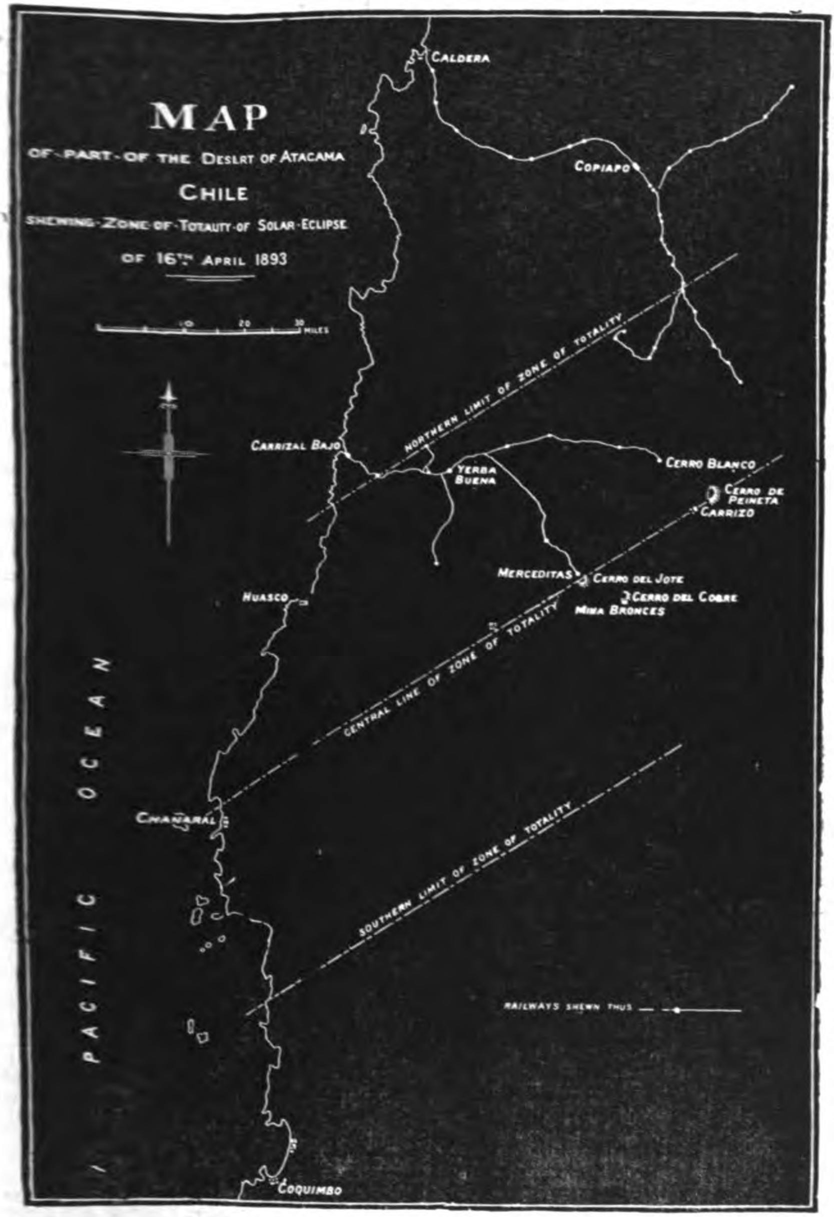
MAP
OF PART OF THE DESERT OF ATACAMA
CHILE
SHEWING ZONE OF TOTALITY OF SOLAR ECLIPSE
OF 16TH APRIL 1893
10 20 30 MILES
CALDERA
COPIAPO
NORTHERN LIMIT OF ZONE OF TOTALITY
CARRIZAL BAJO
YERBA BUENA
CERRO BLANCO
CERRO DE PEINETA
CARRIZO
MERCEDITAS
CERRO DEL JOTE
CERRO DEL COBRE
MINA BRONCES
HUASCO
CENTRAL LINE OF ZONE OF TOTALITY
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FIG. 3.

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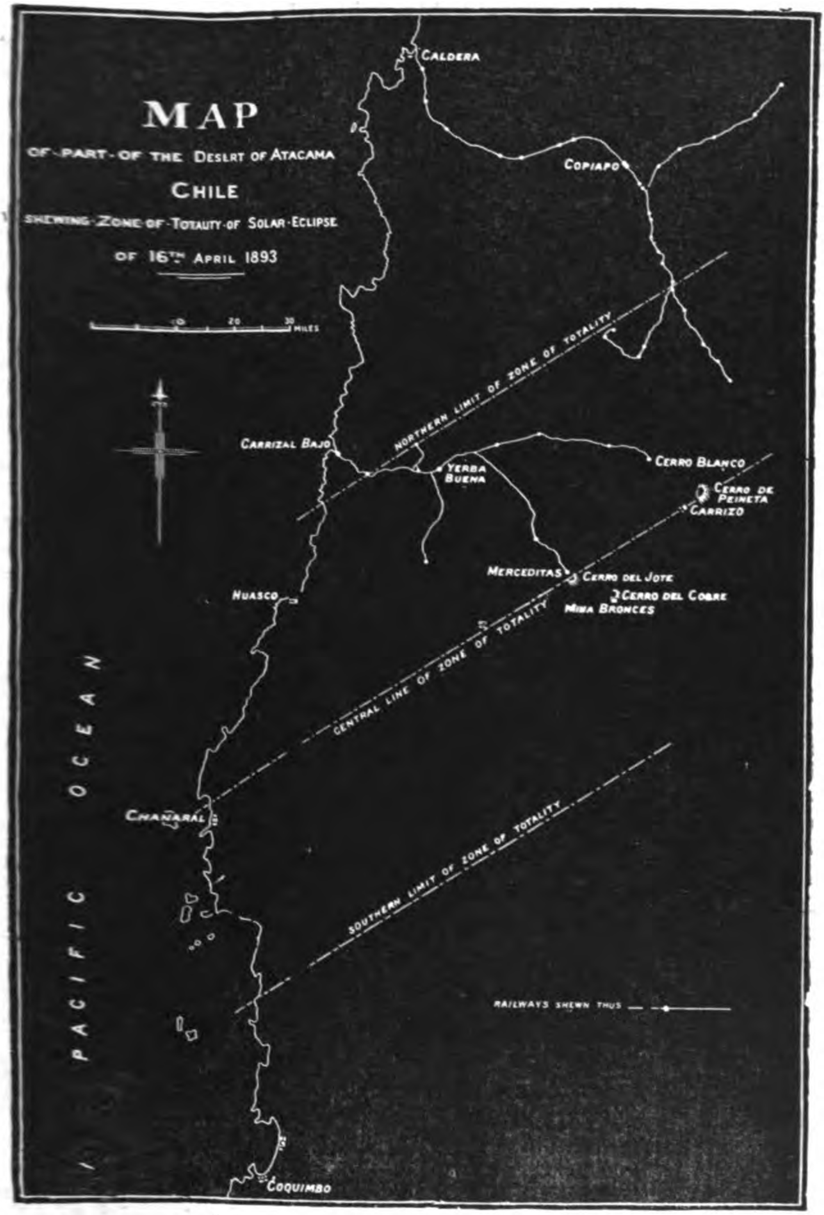
MAP
OF PART OF THE DESERT OF ATACAMA
CHILE
SHEWING ZONE OF TOTALITY OF SOLAR ECLIPSE
OF 16TH APRIL 1893
10
20
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MILES
CALDERA
COPIAPO
NORTHERN LIMIT OF ZONE OF TOTALITY
CARRIZAL BAJO
YERBA BUENA
CERRO BLANCO
CERRO DE PEINETA
CARRIZO
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CERRO DEL COBRE
MINA BRONCES
HUASCO
CENTRAL LINE OF ZONE OF TOTALITY
PACIFIC OCEAN
CHAÑARAL
SOUTHERN LIMIT OF ZONE OF TOTALITY
RAILWAYS SHEWN THUS
COQUIMBO

FIG. 3.

NEWS AND NOTES.

Popular Astronomy.—There is little doubt but that the demand for popular instruction in astronomy is increasing constantly. This is seen in the attitude of teachers of this branch in secondary schools; in the rapidly growing numbers of students and amateur astronomers, in the multiplication of small telescopes, and in the general popular interest in astronomy everywhere. Those who conduct this journal have been profoundly impressed with this fact for some time in the past, but have seen no definite way in which to meet wisely and effectively this most rational demand of those who need and greatly desire the popular and student lore of astronomy. The oldest and broadest field of the sciences certainly has material enough to supply any such demand if it was a thousand fold larger. Every astronomer knows this. Every intelligent student believes it, and every earnest thinker and worker in science has a right to ask for common property in this noble heritage of astronomical knowledge that has come down to us from most ancient times.

Astronomy Popularized.—The main question then is how can astronomy be popularized so as to meet existing needs, and come within the range of self-instruction for those who care enough about it to do anything to gain the knowledge desired It is evident, in the first place, that those who can instruct in this way, and are willing to do so, should be brought into closer relations with those who are to be instructed. This can be done most generally and effectively by a suitable monthly publication devoted to this kind of work. Such a publication should be issued ten times a year, continuously during the months that schools and colleges are in session and omitted during the months of July and August. Teachers and students would then be provided with courses of study and observation of objects that might be seen, on any clear night, by the naked eye, the opera-glass and the small telescope, at the time, while they are reading and thinking about them. What teacher or advanced student does not know that astronomy learned from books only is short-lived at best? It is all so easily forgotten, if it must be remembered chiefly, as a series of facts and pictures seen on the printed page. But if the student can see and picture for himself, in orderly way, the important things in astronomy that he is prepared to think upon, and which he can largely comprehend, who does not know that interest and enthusiasm would be aroused by such a natural method of study and work that could not be secured in any other way, except under the personal guidance of a competent instructor. It would be very easy to give instances of self-instruction in this same general way, only under less favorable circumstances. Some of our greatest astronomers of the present time have come to eminence by very rough ways. What has been done under a stress of unfavorable circumstances by a few, might be accomplished by many more, if judicious and timely aid were offered to direct willing energies for rapid progress.

Amateur Study of Astronomy.—Since we have understood the views of prominent educators from different parts of the United States as learned from a discussion recently held in Chicago, on the requisites for admission to college in astronomy, we are the more interested in presenting some better plan to show the educating power of the elements of this science. Briefly stated it is this:

1. Study by topics with observation. The six topics chosen for the begin-

ning of study would be, the stars, Moon, planets, Sun, comets, and nebulæ, in this order, or any other when observation is most favorable, for they do not so depend on one another that confusion would arise if any order is pursued which would bring most aid by observation. The means of observation would be by naked eye, opera glass and the small telescope. There is abundant work for each and all these instruments. We will later speak of the details.

2. A monthly publication with the title *Popular Astronomy*, intended for students, teachers and amateurs and in no sense professional, except to be accurate in statement of fact, and principle without being technical in terms. It should contain at least 48 pages each month chiefly giving such matter as may be needed by the classes above named. Such a publication should be exactly what is needed to furnish a guide for self-instruction in the elements of astronomy to those for whom it is written. It should be a medium for queries and answers for methods of work, facts, books, and theories to supply individual wants. Its writers should be the best that can be procured for compensation. Its illustrations should be ample and thoroughly accurate. A full series of star maps should be furnished though the expense incurred would be heavy. The cost of starting such a publication would be at least $1,000, but the good work that it would begin and perpetuate can not be estimated in that way. We are ready to undertake this new publication provided one hundred teachers of astronomy, students and amateurs will unite with us and secure ten subscribers each at a uniform price of $2.50 per year. We can be ready to issue the first number for the month of September, 1893. Correspondence is solicited from every one interested in this new venture.

Lunar Photography.—In an article recently published in the *English Mechanic* upon double stars and other astronomical subjects by Mr. S. W. Burnham, he takes occasion to reply to some of the statements which have been made regarding the alleged discoveries on the lunar negatives made at Mt. Hamilton. We make the following extract:

"Referring to the Moon photographs taken at Mount Hamilton with a 36-inch refractor, alluded to by "F. R. A. S.," and the question of alleged discoveries in the positives of "rivers," which have been called in question by M. Prinz, of the Royal Observatory at Uccle, I would suggest the best way of determining whether these details really exist is to examine the lunar surface under the same illumination with any convenient telescope. A very moderate aperture will be sufficient for the purpose. All that is shown on these or any other photographs of the Moon, can be seen with instruments in the possession of most amateurs, and certainly many of them will show scores of details not found on the negatives. At present photographs of the Moon and planets, however large may be the aperture with which they were made, have only a pictorial value. They may be of some interest as showing general areas of the Moon, but cannot compete with other methods of delineating the details which are shown under favorable circumstances to the eye in apertures of 6-in. and upwards. The photographs of the Moon made with the Lick telescope, when compared with what can be seen with the eye with very much less optical power, are precisely the same as the photographs of Jupiter, Saturn, Mars, etc., when compared with what would be obvious to the eye with the same inferior instrument. To those who have made any photographic experiments in this line, or who have examined with any care the results obtained by others, independent of the claims made of their scientific value, this is too obvious to admit of argument.

Nothing whatever is gained by enlarging an original negative, aside from making a picture which requires a less close inspection. Nothing in the way of details can be shown in the enlargement which is not found in the original. Of course, it goes without saying that many details may be pointed out on these Moon negatives, and others taken with much smaller apertures, which are not shown in any drawings. Hundreds of minute markings could be noted by any skilled observer with a moderate telescope which he would be unable to find on any existing sketches, simply because no one has thought it worth while to reproduce them. These things are in no sense of the word *discoveries*, any more than a faint star shown on a long-exposed plate of the Milky Way is a discovery.

It may be mentioned here that the first series of Moon negatives with the Lick telescope, running through an entire lunation were made by me in 1888. Many of these have been reproduced in various publications since that time, and are familiar to most readers. Though not all of equal excellence, owing to the varied atmospheric conditions under which the exposures were made, many of them were as perfect as could be expected with such an instrument, and so far as I know, nothing better has been done since in the way of definition or otherwise. I have made an extensive use of these and other negatives made since that time for the reproduction of enlarged positives and negatives, lantern slides, etc., and the views given above as to the scientific value of such an application of photography are based upon this work and a careful study of the results.

The time may come when we can make a picture of the lunar surface, or of a planet, as we see it with the same aperture through an eye-piece magnifying three or four hundred diameters; but now this seems a long way off. At present photography no more supplants the observer of planetary and lunar surfaces than it takes the place of the double-star observer in the discovery and measurement of stellar systems.

Professor Barnard at Evanston.—"Astro-photography" was the subject of Professor Barnard's talk at the Evanston Club on the evening of the 15th of March. The audience was a large and appreciative one and the speaker was in his usual happy vein. Nothing aroused more genuine interest than the development of *Swift's Comet 1892*, as shown on the screen.

The power of the method and the skill of the photographer were also beautifully illustrated in the reproductions of the cloud forms of the Milky Way. The *Evanston Club* has a weakness for getting its information first-hand. They recognized in Professor Barnard's learning a soundness and freshness which combined to make it both attractive and adhesive.

Planning for Greater Telescopes.—It is with some surprise that we notice much in current scientific and popular journals of recent date about the manufacture and uses of telescopes very much larger than any now in existence. We did not give particular heed to the earlier notices of this favorable sentiment which began to grow over one year ago, for it then seemed as if but little would be likely to come of it. But later when such astronomers as Mr. Common, and Professor Pickering, and such manufacturers and opticians as Mantois, Clark and Brashear, and others that might be named, began to speak favorably of undertaking to construct telescopes of any size desired, it seemed that our science was taking on new life in a most important sense. Observers will have to stop and think a while and try to make up their minds whether or not the limit of size in the telescope has been reached in view of unsteady atmosphere and the nature of light, so that large increase of magnifying power may be used with possible or probable advantage. It now seems clear that refracting or reflecting telescopes much larger than any now in existence can be made, if those who ought to know have judged rightly, and it is probably true that money is ready to build the largest instrument that can be made, if those who would undertake it could be reasonably assured that the outlay would be of real service to astronomy in penetrating unknown fields of useful research. Now the real question seems to be, can much larger instruments be expected to do much more, or really any more, good work than those of the largest size already in use? If not, it would be very unwise to waste money in such fruitless attempts. But, on the other hand, if there is a reasonable hope of doing *some* more than possibly could be done with existing telescopes by the aid of still larger ones, by all means let us have them speedily. Astronomers experienced in the use of large instruments ought to be able to give useful evidence at this point of study of this important question. They are generally invited to do so through this publication.

Screens to Protect the Telescope from Wind Tremors.—Noticing in the *Astronomical Journal* that Professor Barnard had suggested a system of canvas curtains to cover part of the opening in the dome of the Lick Observatory to secure the great telescope from vibration on account of the direct pressure of the wind upon it, I have written him a note suggesting that a *twine netting with small meshes*,—say, one-half inch square, and made from heavy, strong twine,—may be made in the form of a long screen, large enough to fill the whole slide opening except that part through which the telescope may be pointed. The size of the mesh and the means of attachment and manipulation can be cheaply and easily determined by trial, but when once determined, a flexible wire netting may be substituted, although I should prefer the twine. The canvas will make much noise and the netting will be free from noise.

I have made this suggestion because I know from many years of experience that a high paling fence breaks up the direct force of the wind completely. I learned the trick long ago when using brush to protect my tents from heavy southeasters. I recommended it to Mr. Woodward, proprietor of the Woodward Gardens of San Francisco, and he completely protected the Gardens by an open fence that must now be thirty feet high. Visitors on the exposed Meiggs Wharf at San Francisco will remember what an unexpected protection the adoption of the eight foot paling fence on the windward side afforded them in the most violent summer winds tearing through the Golden Gate.

I am sure that in all these observations in which the telescope is vibrated by the direct force of the wind there will be found almost absolute quiet if the proper size of mesh is secured; and that the temperature will be very slightly, if at all, changed.

GEORGE DAVIDSON.

A Note on the Draper Catalogue.—When writing my former articles I had not seen the introductory volume to the *Draper Catalogue* nor was I aware of its existence though it bears the date of 1891. There are two useful tables in it arising from the variances as to the spectra of certain stars between the *Draper Catalogue* and the observations of Vogel and Konkoly respectively. Professor Pickering had these spectra re-examined with photographs of longer exposure and the result is between 200 or 300 corrections. This result suggests a very large number of corrections if the entire catalogue had been re-examined. A considerable number of spectra classed as A became B in the revised version, but the very small proper motion of stars with this type of spectrum is borne out by the additions. The spectrum E often passes into G with longer exposure, and I think there is no doubt that stars with this latter spectrum are referable to the Capellan not the Arcturian class. The corrections chiefly occur with the fainter stars and scarcely produce any effect on my analysis of Auwer's Catalogue (reversed by Herz and Strobl) which appears in ASTRONOMY AND ASTRO-PHYSICS for December 1892. The changes in the Pulkova Catalogue are somewhat greater. I have found some other errors in my analysis in this case and I think it would be improved by striking out all stars which appear also in the catalogue of Auwers so as to have two independent results. I propose therefore to forward an amended analysis of the Pulkova Catalogue when I have time to complete it.

I doubt the validity of Professor Pickering's conclusions as to the structure of the Galaxy. They seem to me to depend in a great measure on the selection of the stars in the *Draper Catalogue* which is not an impartial one as regards different parts of the sky. It omits northern stars brighter than the 5th magnitude and includes others not much brighter than the 8th. Statistics founded on such a catalogue are of very little value. We require either completeness or impartial selection to ground valid inferences on. . W. H. S. MONCK.

Removal of Warner Observatory from Rochester, N. Y.—Replying to your inquiry if the Warner Observatory is to be removed from Rochester, I answer, yes. Though the matter is yet unsettled owing to the prolonged absence in Europe of its founder, yet it may not be amiss to give the readers of your journal the reasons which lead to so extraordinary an event. Not to go too much into detail at this time, I will say they are three: (1) The erection of a large church with steeple and five heated chimneys adjoining the Observatory lot on the west has to a great extent destroyed the view in that direction. (2) The vast number of electric street lights entirely surrounding the Observatory, from a few rods to three miles distant, has so ruined the work of the discovery or observation of nebulæ that, practically, it has been abandoned. When the ground is covered with snow and the trees denuded of their leaves, the sky illumination almost equals that from a gibbous Moon. (3) The frequent and long continued cloudiness of the sky in this region, surpassing in this respect every place in the country save Vancouver, calls for its removal to a more propitious climate.

Where will be its future location is not yet decided, but, probably after Mr. Warner's return, one of the many sites offered will be personally inspected and chosen. Invitations have been received from Texas, New Mexico, Arizona, California, Colorado, Missouri, Iowa and Nebraska. My desire is to locate farther south, as between the equator and 38° of north latitude there lies a belt encircling the globe on which no large telescope has ever been used. LEWIS SWIFT.

Warner Observatory, Rochester, N. Y.,
March 12, 1893.

New Telescope for Drake University.—For the last two years Professor W. A. Crusenberry, of Drake University, Des Moines, Ia., has been pursuing the post-graduate course of study in mathematics and astronomy offered at Carleton College, spending a considerable portion of his summers at Goodsell Observatory in regular observing. His progress in practical astronomy has been rapid and most encouraging to himself, considering the fact that he has carried all his regular college duties at the University in the mean time. In view of his unusual efforts for better preparation for instruction and work in astronomy, the many friends of Drake University and Professor Crusenberry in particular, will be gratified to learn that General Drake, the founder of the University that bears his name, has given the means for the purchase of a new telescope which is to be ordered immediately. Professor Crusenberry is now in correspondence concerning the size of glass, kind of mounting and apparatus to go with it. When a good man is thoroughly ready to do good work the way will be opened for him.

Honors for E. E. Barnard.—It was an historical event for all concerned, when on March 8th, 1893, before a large audience at Vanderbilt University, Nashville, Tenn., Chancellor Garland, the venerable head of the university, conferred on E. E. Barnard of Lick Observatory, the degree of Doctor of Science, in behalf of the Faculty of that institution. It was a delightful surprise and was greeted by enthusiastic applause.

In delivering the diploma Dr. Garland told the story of Professor Barnard's life: First, an untutored boy, applying for a situation in a photograph gallery; then a youth of splendid efficiency in the art rooms, where he spent his days, while at night whenever the skies were clear he might be found on the roof of the gallery studying the stars through a small telescope; next, a young man at Vanderbilt University laboring by day in books of science and at night having free access to the university telescope; suddenly famous throughout the country as a discoverer of comets; then chosen to be one of the observers at the Lick Observatory, Mt. Hamiliton, Cal., where stands the finest and largest telescope on earth, and now a man whose name will go down the ages beside that of Galileo because of his discovery of the fifth satellite of Jupiter.

On the following evening Dr. Barnard was royally banqueted by his many friends of Nashville.

The Structure of the Galaxy.—The list of the Galactic Longitudes and Latitudes of stars given by Mr. Marth in the *Monthly Notices* of the R. A. S., enabled me to test to a certain extent the theory that the Galaxy is a collection of Sirian stars, the solar stars being pretty uniformly distributed over the sky. The list only contains 180° of Galactic longitude but we are promised the remaining stars in a future number when I may be able to give you more definite results. The following is a rough analysis of the stars from the Harvard Photometry (not exceeding magnitude 6.0) comprised in Mr. Marth's list. For latitudes of more than 20° the list is evidently incomplete. (The Galactic longitudes are in all cases 0° to 180°).

Latitudes (Galactic)	Sirian	Capellan	Arcturian
0° to 5°	162	41	66
5 to 10	140	33	66
10 to 15	115	25	54
15 to 20	121	35	55
over 20	52	15	38

Considering the narrowing of the zones as we proceed to higher latitudes I think there is very little trace of condensation of any class of stars in the region of the Galaxy, nor do the proportions between the different classes of stars vary considerably during the first 20° of Galactic latitude on either side.

The type B is included as Sirian. The relative numbers of stars with this type under the 5 heads are 12, 10, 12, 11 and 3, thus showing no aggregation. The numbers for type M are 6, 7, 3, 7 and 5 respectively. W. H. S. MONCK.

Dublin, March 1st, 1893.

Errata.—Page 211, line 29, read diameter for surface.

The last term of equation 6 above should be

$$2.5 \log \left[\frac{S}{S'}\right]^2 \text{ instead of } 2.5 \left[\frac{S}{S'}\right]^2.$$

Last line page 303, for Anniuare, read Annuaire.

Wolsingham Observatory.—The report for the year 1892 has been received. It shows that 116 new third type stars and one variable star have been found in zones + 55° and 56°. In the autumn, the telescope was entirely devoted to the revision of double stars in connection with the forth coming edition of "Celestial Objects for Common Telescopes." Of this work Mr. Espin says:

It may be interesting here to note the general scheme of the new edition. The planetary and solar portions will remain untouched, saving the addition of new matter in foot notes. As it was felt that this was work that could be only satisfactorily done by specialists, Miss Brown was asked to look over the pages assigned to the Sun; Mr. A. Stanley Williams, Mercury, Venus, and Mars; Mr. Elger, the Moon; Mr. Waugh, Jupiter; Mr. Freeman. Saturn; Mr. Denning, Comets and Meteors—on which a short chapter will be added. Celestial Photography and Spectroscopic work will also have short chapters assigned to them. The work will be divided into two volumes, the first containing the Sun and Planets. The second volume will contain Double Stars, &c. This will be entirely re-written, and the objects arranged in each constellation in order of Right Ascension. The measurements and magnitudes of Struve will be substituted for those of the Bedford Cycle, as this work has been so ably re-edited by Mr. Chambers. It must be remembered that Prebendary Webb's scheme was a two-fold one: To give objects interesting from their motion and also to record remarkable groupings and colors. The work of selecting new objects was one of considerable difficulty; but it has been thought best to confine them to a definite magnitude, and this has been fixed by the brightness of the Primary. All double stars will, therefore, be included, whose Primary is above 6.5 mag. and whose distance is less than 20 seconds. Some new groupings and pairs of marked color will be inserted; but it is felt that in this respect, the former edition was fairly complete. By the end of the year the selection was completed, and the work of bringing up the whole of the places to 1900 for the first twelve hours was finished, while considerable progress had been made in those between 12 and 20. Much valuable assistance and many suggestions for the new edition have been received, and, besides those already mentioned, my thanks are due to Messrs. Ranyard, Sadler, Burnham, Schiaparelli, Perrotin, Leavenworth, Gore, and Captain Noble, and the Astronomical and Physical Society of Toronto.

The report contains considerable other work of various kinds showing that Director Espin has been busy during the last year.

Poole Brothers Celestial Handbook and Celestial Planisphere.—This new work is compiled and edited by Jules A. Colas and published by Poole Brothers of Chicago. The handbook contains 110 pages with a great number of fine illustrations. It is printed on heavy plate paper and is a neat specimen of the printer's art. The themes are: Introduction, constellations north of the zodiac, constellations of the zodiac, constellations south of the zodiac, old and new constellations in chronological order, names of the principal stars, principal binary stars, finest double stars, stars of known parallax, stars of greatest proper motion, shooting stars, comets, planets, and indexes with two large plates. The accompanying planisphere is on a heavy card board 23 inches by 18.5 inches. The movable circle which is a map of the constellations, stars, and other celestial phenomena is 19.5 inches in diameter with North Pole as center, and extends to the 50th degree south of the Equator. It shows stars down to, and including, the fifth magnitude. The boundaries of the constellations are plainly marked and auxiliary lines are given as aids for star-tracing. At another time, we will speak more at length of this very useful planisphere. There are some points of improvement that make it superior to any other we have seen.

Observational Astronomy is the theme of a book in quarto form, consisting of about 86 pages and is intended for beginners. Its author is Arthur Mee. It was published by Daniel Owen & Company, Cardiff, 1893. Price 2s. 6d.

The book is an attempt to work out a capital idea. It contains, for the amateur, much late and useful information. It is amply illustrated, but we are sorry to see, that much of this part of the work is inexcusably bad. We can not imagine any reason why an author of the apparent ability of Mr. Mee should be obliged to use so many poor illustrations.

Logarithmic Tables by Professor George William Jones of Cornell University is a book first issued in 1889, and the copy now before us is the fourth edition. It has been enlarged by the addition of twelve new tables, and the whole matter has been re-set, and it is really a new book. The tables are on large open pages and in very clear, easy type. The eighteen tables presented are as follows: Four-place logarithms, four-place trigonometric functions, logarithms of numbers, constants of mathematics, and of nature, weights and measures, addition-subtraction logarithms, sines and cosines of small angles, trigonometric functions, natural logarithms, prime and composite numbers, squares, cubes, square roots, cube roots, reciprocals, quarter-squares, Bessel's coefficients, binomial coefficients and errors of observation.

Professor Jones has prepared an excellent book, as far as it goes, and there is reason to believe that its tables are very generally accurate. He has taken great care to insure accuracy in every particular, and so far as we know he has succeeded admirably.

Astronomical and Physical Society of Toronto.—At the last meeting reported communications to the society were read from L. Neiston, Royal Observatory of Belgium, Dr. R. Ball of Cambridge, England, and Dr. M. A. Veeder. Mr. Veeder called attention to the fact that the outburst of Holmes' comet which occurred Jan. 16 was coincident with the appearance of an enormous sun-spot on the eastern limb of the Sun. He thinks the luminosity of comets' tails is due largely to electro-magnetic conditions and at the time mentioned they were marked in character. Reports of the committee on the astronomical day, of observations, and of brilliant meteors were made. The paper of the evening was read by Arthur Harvey; theme, the telescope, giving something of its history and its enlarged field of work in modern times.

New York Academy of Sciences.—Section of Astronomy and Physics. Minutes of the Meeting, 1893, March 6. The Section was called to order at 8:20 P. M., Professor Rees in the chair. A paper was read by Mr. C. A. Post on "A New Driving Clock for Equatorials." The apparatus described has been in successful operation for more than a year. It involves a new method of control (not electric), and a new differential slow motion for photographing. This slow motion can be applied in either direction without stopping the clock, or changing its rate.

Mr. Jacoby communicated the results of some measures made by him upon Mr. Rutherfurd's plates of β Cygni. These additional measures seem to confirm the existence of a large parallax for this star.

Professor Rees exhibited a photograph of a meteor trail, recently obtained by Mr. John E. Lewis, of Ansonia, Conn. HAROLD JACOBY, Secretary.

PUBLISHER'S NOTICES.

The subscription price to Astronomy and Astro-Physics in the United States and Canada is $4.00 per year in advance. For foreign countries it is £1 or 20.50 marks per year, in advance. Recent increase in price to foreign subscribers is due to increase of postage because of enlarged size during the year 1892. Messrs. Wesley & Son, 28 Essex Street, Strand, London, are authorized to receive subscriptions. Payment should be made in postal notes or orders or bank drafts. Personal checks for subscribers in the United States may be used.

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For information of correspondents, the names and addresses of the associate editors of Astro-Physics are given as follows:—

James E. Keeler, Observatory, Allegheny, Pa.; Henry Crew, Northwestern University, Evanston, Ill.; Jos. S. Ames, Johns Hopkins University, Baltimore, Md.

All matter or correspondence relating to General Astronomy, remittances, subscriptions and advertising should be sent to Wm. W. Payne, Publisher and Proprietor of Astronomy and Astro-Physics, Goodsell Observatory of Carleton College, Northfield, Minn.; and the Associate Editors for General Astronomy are: S. W. Burnham, Government Building, Chicago Ill.; E. E. Barnard, Lick Observatory, Mt. Hamilton, Cal., and H. C. Wilson, Goodsell Observatory, Northfield, Minn.

Manuscript for publication should be written on one side of the paper only and *special care should be taken to write proper names and all foreign names plainly*. All drawings for publication should be *smoothly* and *carefully* made, in *India Ink* with lettering well done, because such figures are copied exactly by the process of engraving now used. If drawings are made about double the size intended for the printed page, better effect will be secured in engraving than if the copy is less in size. It is requested that manuscript in French or German be typewritten. If requested by the authors when articles are sent for publication, *twenty-five* reprint copies, in covers, will be furnished free of charge. A greater number of reprints of articles can be had if desired, at reasonable rates.

Rates for advertising and rates to news agents can be had on application to the publisher of this magazine.

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Astronomy and Astro-Physics.

VOL. XII, No. 5. MAY, 1893. WHOLE No. 115.

General Astronomy.

METEORIC ASTRONOMY.

I.

THE LEONIDS, OR METEORS OF NOVEMBER 13.*

DANIEL KIRKWOOD.†

Within the memory of persons now living shooting stars were regarded as gaseous matter generated in the atmosphere. Their true nature was wholly unknown, and works on astronomy made no attempt to account for their origin.

The most brilliant display of these phenomena recorded in history occurred on November 13, 1833. Few persons of the present day remember the scene as then witnessed. A shower of fire, indeed, is not to be forgotten, but the interval of 60 years has left the number of spectators small. Throughout a large part of North America the atmosphere on the night of the display was remarkably clear. The unusual frequency of meteors was noticed as early as eleven o'clock on the night of the 12th. As the night advanced their numbers rapidly increased, till all attempts to count them were entirely abandoned. Thousands of observers, from Greenland to Florida—from Behring's Strait to Panama, looked on with increasing wonder from midnight to daylight. The meteors appeared to radiate from a particular point in the constellation Leo. Their apparent magnitudes varied from the smallest visible particles to that of the full moon. Their brilliancy was such that persons sleeping in rooms with uncurtained windows were aroused by their light. Occasionally one of the larger masses separated into parts, and some fragments are said to have remained visible for several minutes. In some parts of the country the ignorant and superstitious were completely terrified, imagining that the last day was about to break upon the world. The wonderful appearance presented a new problem for

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* Communicated by the author.

† As the closing years of the nineteenth century are to witness a display of the November meteors, the following paper may have a timely interest.

scientific investigation. Shooting stars had indeed been seen i all ages of the world, but they had been looked upon as simpl atmospheric phenomena. It was now seen, however, that th meteors of November 13 did not move in harmony with the ancient theory. A new discussion of facts was accordingly undertaken by prominent astronomers. Among its leaders were Professors Olmsted and Twining of Yale College, Olbers and Erma in Germany, with others no less eminent both in Europe an America. The origin of Meteoric Astronomy, as a science, date from this epoch. It was remembered by a few persons that a the same date in the previous year, 1832, an unusual number o meteors were seen, though the display was much less brilliant It was perceived, therefore, that this coincidence of dates coul be best explained by supposing a train of cometary matter t cross the Earth's path at the point passed by it on the 13th o November. The fact was also recalled that Humboldt had witnessed a similar display though less remarkable, in South America, November 12, 1799; thus confirming the theory of a cometary or nebulous intersection of the Earth's orbit, and indicatin a period of 33 or 34 years. The *American Journal of Science* fo 1864 contains the elaborate researches of Professor H. A. Newto in regard to former displays of the November meteors. The lis extends backward through a thousand years, including the date 1698, 1602, 1533, 1366, 1202, 1101, 1002, 934, 931 and 902 The shower of 1366—almost equal to that of 1833—is thus described in a Portuguese chronicle quoted by Humboldt:—

"In the year 1366, twenty-two days of the month of Octobe being past, three months before the death of the king, Don Pedr (of Portugal), there was in the heavens a movement of star such as men never before saw or heard of. At midnight, and fo some time after, all the stars moved from the east to the west and after being collected together, they began to move, some i one direction and others in another. And afterward they fel from the sky in such numbers and so thickly together, that a they descended low in the air they seemed large and fiery, aud th sky and the air seemed to be in flames, and even the Earth appeared as if ready to take fire. That portion of the sky wher there were no stars seemed to be divided into many parts, an this lasted for a long time."

With the average time of revolution (33¼ years), the perihelio being at the Earth's orbit, it is easy to calculate the meteori path around the Sun, as represented in Fig. 1.

The return of the November meteors have been either after inter vals of 33 years, or after some multiple of that period. A return in 1866 or 1867 was accordingly predicted. The shower was witnessed in Europe in the former year and in America in the latter. The fact that the phenomena extend over two or three years merely indicates the gradual diffusion of the meteors along the orbit, so that several years are required for the entire cluster to pass any particular point of the path.

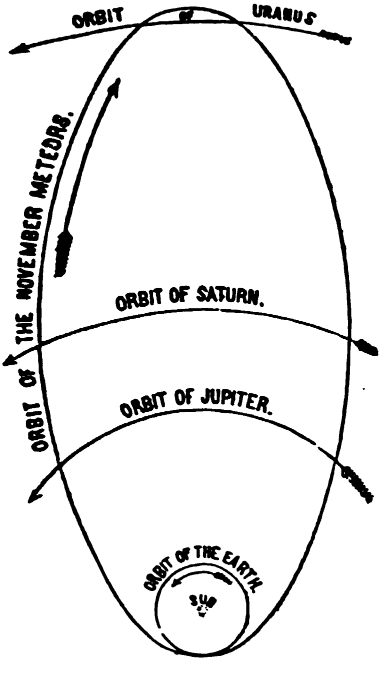

Fig. 1.

Origin of the Meteors of November 13th. In December, 1865, less than a year before the great showers of the November meteors, a comet was discovered moving in the same path, in the same direction, and having the same period. This coincidence could not have been accidental. It was accordingly concluded that the meteoric cluster was derived from the comet; that the latter is undergoing the process of dissolution; that the cometary matter is being slowly distributed around the orbit; that the comet will thus finally disappear and manifest itself only as yearly showers of the November stream.

Height of Meteors. The observations of Professors Newcomb, Harkness and Eastman, of the U. S. Navy, on the 12th, 13th and 14th of November, 1867, decided, at least approximately, several questions of importance. A line from Washington, D. C., to Richmond, Va., furnished a convenient base for the determination of parallax. It was found that the meteors first became visible at an average altitude of 75 miles; the maximum probably not much exceeding 100 miles. The average height at extinction was about 55 miles; the latter elevation being greater than the previously estimated height of the atmosphere. As the meteors of this swarm have retrograde motion, or, in other words, meet the earth in its path, they have the extraordinary relative velocity of 44 miles per second. This rapid motion, even in an atmosphere extemely rare, produces an intense heat of the moving particles. The brilliancy of many was very remarkable. In a majority of instances visibility lasted but a fraction of a second.

During the thickest part of the shower (1867) the meteors were counted at the rate of 50 per minute, or one nearly every second. These small bodies are burned up or dissipated long before reaching the Earth's surface. The results of combustion, however, may, at least in part, be ultimately deposited as solid matter. The weight of the individual meteoroids cannot be given with any degree of accuracy. They are known, however, to be very minute, and Professor Newcomb remarks that if we assume a mean weight of a single grain "the entire mass of the stream may be rudely estimated as equal to that of a mass of iron 400 feet in diameter."

Such has been the development of meteoric astronomy. A *pseudo* science of atmospheric phenomena, it has, within three quarters of a century been transferred to the heavens. From tracing the "mystic dance" of *ignes fatui*, it has risen to trace the curves of comets and of stars. In determining the cometary period, Professors H. A. Newton, of Yale College, and J. C. Adams, of Cambridge, England, held each a conspicuous place. The former showed the period to be 180.05 days, 185.54 days, 354.62 days, 376.5 days, or 33.25 years. He showed, moreover, how it was possible to determine which of the five periods is the correct one. This crucial test was applied by Dr. J. C. Adams, who, by an elegant analysis, proved the last named period to the true one. * Professor Newton has traced the history of the Leonids for a thousand years—from A. D. 900 to the present time. Its ancient track is more obscure, but an occasional glimpse may perhaps be caught as it moves down successive ages. Were the cometic matter uniformly distributed around the orbit a display would be an annual occurrence. A few sporadic outriders of the cluster are sometimes found, and rarely, larger groups have been noticed. Two have been specified by by the present writer. † *When may we expect the next shower from this celebrated cluster?* The average period, as we have seen, is 33.25 years, and the display is continued through at least three consecutive years. We may therefore expect it in 1899, 1900, and 1901. In former times it not infrequently escaped observation. The meteoric fall sometimes occurred in the daytime, sometimes in cloudy weather, and sometimes over the

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* *Monthly Notices* R. A. S. for April, 1867.

† See Payne's Sid. Mess., Oct. 1885. Also Chambers' Astr., Vol. I, p. 632.

ocean, or over uncivilized countries. The probability of such failures is now less than in former ages. In short, if we live and retain our sight for the next six or seven years we shall no doubt have the pleasure of seeing at least one grand meteoric shower.

It will also be highly interesting to astronomers to watch the comet of 1866. the body associated with these November meteors—the comet moving with them, and from which they are derived. As it has for centuries been subject to a wasting process it was doubtless larger in ancient times than at present. In 1366 and at some other returns before the invention of the telescope, it seems to have been seen by the naked eye. The meteors were less widely spread, and, of course less frequently seen.

THE METEOR COMET OF 1866.

Tempel's comet of 1866 was not visible to the naked eye. It is to be remarked, however, that the apparent magnitude at any return must depend on its relative position with respect to the earth, and also that for a thousand years or more it has been undergoing the process of gradual dissolution. It was a naked-eye comet in 1366 and 868. Other dates also correspond with remarkable exactness to those at which the maximum cluster passed perihelion. Oppolzer's period is 33.176 years, and Newton's for the associated meteors is 33.25 years. The striking agreement of dates at which the maximum cluster passed the perihelion is thus represented:

From	1366	to 1866	15	periods of	33.28	years.
"	1266.8	to 1366.8	3	"	33.33	"
"	1133.8	to 1266.8	4	"	33.25	"
"	1067.4	to 1133.8	2	"	33.20	"
"	1000.9	to 1067.4	2	"	33.25	"
"	868.1	to 1000.9	4	"	33.20	"
"	834.8	to 868.1	1	"	33.30	"
"	668.4	to 834.8	5	"	33.28	"
"	602	to 668.4	2	"	33.20	"
"	436	to 602	5	"	33.20	"
"	336	to 436	3	"	33.30	"
"	269.7	to 336.1	2	"	33.20	"
"	69.7 (?)	to 269.7	6	"	33.30	"
B. C.	295 (?)	to 69.7	11	"	33.20	"

The mean length of the 65 periods, included in the foregoing list is 33.25 years—Newton's period of the meteors; or, if we reject the comet of 295 B. C. as doubtful, we have 54 periods of 33.26 years.

The phenomena of the Leonids fix the dates at which the maximum cluster intersects the earth's orbit, and hence the time of perihelion passage may be inferred. They indicate also what parts of the ring are destitute of meteoroids; what parts are thinly, and what more densely filled with meteoric matter. A separate group of Leonids has thus been found preceding the main cluster 12 or 13 years.* An ancient display from this secondary cluster is given by Quetelet *Sur La Physique du Globe, p. 290.* The date was A. D. 288, Sept. 28. A phenomenon from this cluster is also given by Hind for 855 and again in 856. Another, 1787, is given in Humbolt's Cosmos, Vol IV. Later sparce showers are mentioned by Chambers. "It is thus that highly important consequences may be expected to be traced from these and similar investigations and discussions; indeed, the subject may perhaps fairly be deemed an inexhaustible one, for a few coincidences having been ascertained, more will be sure to follow as observations multiply and research extends."†

JUPITER'S SATELLITES.‡

WILLIAM H. PICKERING.

Although we are now in the midst of our rainy season, I have been able to continue my observations upon the satellite system at intervals, and have acquired some further information. The satellites taken as a whole have developed so many unexpected phenomena, and what have appeared to be the most natural suppositions have been found so frequently to be contradicted by the facts, that it seemed best to take nothing for granted with regard to them. For this reason it appeared most desirable to determine if possible whether their rotation upon their axes was direct or retrograde. The detail exhibited by their surfaces, excepting in the case of the 3rd, is so difficult that little reliance can be placed upon observations of it, and for the other satellites at least, this method must be discarded.

At first sight it does not seem possible to determine the direction of rotation of a body by simply watching the alternate lengthening and shortening of its disc. Nevertheless, a little consideration will show that it is quite possible theoretically, and the practical solution of the problem depends merely upon the accuracy of our observations. The phenomenon which comes to our assistance at this juncture is the revolution of the Earth in its orbit, for it is quite evident that after the opposition of the planet, if the direc-

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* Chambers' Descriptive Astr., Vol. I., pp. 631-2.

† Chambers.

‡ Communicated by the author.

of the rotation of the satellite is direct, it will present a phase rather earlier than it would do if our observations een made from the center of the Sun. On the other hand is direction of rotation is retrograde, the presentation of the e will be somewhat delayed. With the solution of this ques- in mind I have made a preliminary reduction of our obser- ns upon the 1st satellite, of which I will give a brief psis in what follows. The observations are made in Are- a meantime, the longitude of Arequipa being approximately 5^{m} 30^{s} from Greenwich.

ow is given as a sample the last series of observations made. as found that the impression of the shape of the disc as seen he eye gave a much more accurate determination of the d, than could be obtained by a series of micrometric measure- s of its length. This will be readily understood when it is dered that the total variation in length in the course of hours amounts to little more than 0″.1, while a difference een the two diameters amounting to only 0″.01 can be de- d by a direct comparison, as is shown by the observations:

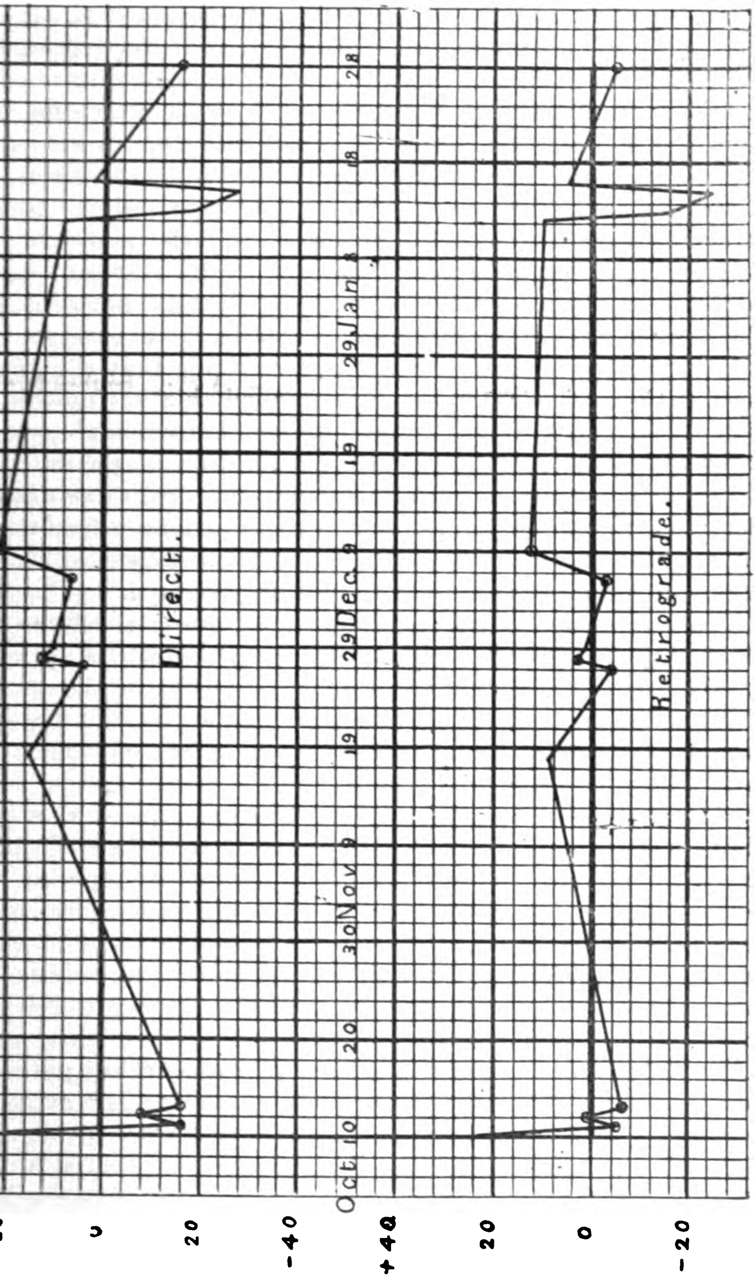
Saturday, January 28, 1893.

^{m} (Watch) 1st satellite long (*i. e.* disc elliptical). Seeing 3 to 4 (5 perfect).
1st getting rounder, almost orange colored.
1st still a trifle longer than Jupiter (*i. e.* in proportion to its size).
1st getting shorter.
1st still long.
1st long.
1st not quite as long as Jupiter probably.
1st almost round.
1st no shorter.
1st nearly round. Seeing 4.
1st circular.
1st perfectly circular. Seeing 4.
1st perfectly circular. Seeing 4.5.
1st almost elliptical. Haze thicker.
1st I think getting elliptical. Hazy.
1st elliptical, but very hazy.
1st hazy but very clearly elliptical. Circular at 8:40 by watch, or 8:39 by M. T. clock.

om the above it will be seen that to obtain a satisfactory s of observations requires about two hours, and that conse- tly at the present time, unless the circular phase occurs very in the evening no complete series can be made. From the le of October to the middle of November Mr. Douglass and I absent from the observatory. On my return I had hoped to he photographic routine work completed, but as it was not, to do it myself, which occupied another month. Thus it een possible to obtain but comparatively few series of obser- ns of this phenomenon this year. These however are given e following table. Sixteen series were obtained in all, of which eight are considered satisfactory and are weighted 2 seven are considered unsatisfactory usually because the observa tions either before or after the circular phase were incomplet One series was rejected since but two observations were mad within forty minutes of the proper time and they led to a man festly erroneous result, the circular phase having been suppose to occur after them, when it had really occurred at some time b tween them.

In the following table the first column gives the current numbe the second the observed Arequipa Mean Time of the circula phase, the third the weight attached to the observation, and th fourth the number of rotations that had occurred since the firs accurate observation, upon October 11. The next three column are based on an assumed direct rotation of the satellite, the firs being the observed time reduced to the center of the Sun, th second the theoretical time assuming a uniform rotation, and th third column the difference between the two. The last three co umns give the same results based on a retrograde rotation. Th fourth determination is obtained from a series of observation made by Mr. Douglass. Upon the hypothesis of a direct rotatio the synodic period of the satellite is $13^h\ 03^m\ 25^s.8$, upon the hy pothesis of a retrograde motion it is $13^h\ 03^m\ 10^s.8$:

				Direct.			Retrograde.		
No.	Date.	W.	R.	Obs.	Theory.	D.	Obs.	Theory.	D.
				d h m	d h m		d h m	d h m	
1	Oct. 10 11 31	1	−2	10 11 54	10 11 39	+ 15	10 12 00	10 11 37	+ 23
2	11 13 29	2	0	11 13 36	11 13 52	− 16	11 13 38	11 13 43	− 5
3	12 09 11	2	1.5	12 09 19	12 09 27	− 8	12 09 33	12 09 18	+ 1
4	13 11 10	2	3.5	13 11 18	13 11 36	− 18	13 11 18	13 11 24	− 6
5	15 09 52	0	7	15 10 01	15 09 16	(+ 45)	15 09 59	15 09 05	(+ 54
6	Nov. 14 09 13	1	69.5	14 09 35	14 09 20	+ 15	14 09 23	14 09 14	+ 9
7	27 08 27	2	96	27 08 31	27 08 27	+ 4	27 08 13	27 08 17	− 4
8	28 10 41	2	98	28 11 06	28 10 54	+ 12	28 10 20	28 10 23	− 3
9	29 06 14	1	99.5	29 06 39	29 06 29	+ 10	29 05 59	29 05 58	+ 1
10	Dec. 6 07 34	2	102.5	6 08 20	6 08 14	+ 6	6 07 36	6 07 39	− 3
11	9 07 57	2	108	9 08 23	9 08 02	+ 21	9 07 39	9 07 26	+ 13
12	Jan. 12 07 50	1	170.5	12 08 15	12 08 07	+ 8	12 07 25	12 07 15	+ 10
13	13 09 31	1	172.5	13 09 55	14 10 16	− 19	13 09 05	13 09 21	− 16
14	15 07 04	1	176	15 07 28	15 07 56	− 28	15 06 38	15 07 03	− 25
15	16 09 40	1	178	16 10 04	16 10 02	+ 2	16 09 14	16 09 09	+ 5
16	28 08 40	2	200	28 09 02	28 09 18	− 16	28 08 14	28 08 19	− 5


Direct.
Retrograde.
Oct 10
20
30 Nov 9
19
29 Dec 9
19
29 Jan 8
18
28
0
20
-40
+40
20
0
-20

The average deviation of an observation on the direct hy
thesis is 13^{m}.3, on the retrograde hypothesis it is 8^{m}.6. If w
clude only the complete observations, which are weighted
the table, we find the probable error of a single observatio
the rotation is direct, is 9^{m}.0, if it is retrograde 4^{m}.0. An ins
tion of the differences under the direct and retrograde colu
seems also to indicate a systematic deviation in the former
To make the matter clearer, however, two curves have been
structed, using the dates as abscissæ, and the numbers in
two difference columns as ordinates. If the observations
without error they would lie along a straight horizontal
The complete observations are indicated by small circles.

As a result of these observations, I conclude that the direc
of rotation of the 1st satellite is probable retrograde,—
other unexpected result. The only well-known analogy in
solar system being the retrograde revolution of the satellit
Neptune in its orbit, while following the direct revolutio
Neptune around the Sun. Further observations before the
oppositions should confirm the retrograde rotation of the s
lite by deciding between the two periods proposed.

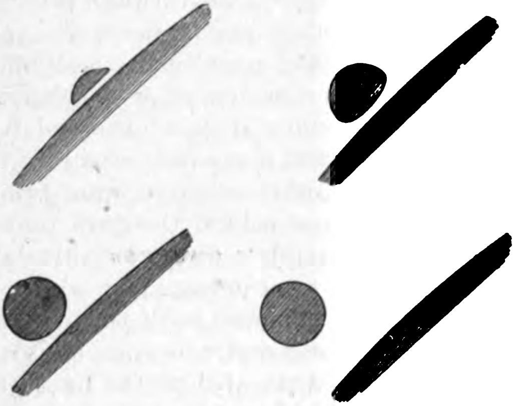
An explanation of the rotation of the outer satellites al
their major axes has recently been found, which is appare
consonant with well-known physical laws, but as the comp
tions necessary to a full development of the theory have no
yet been completed, it is thought best to defer a statement
until a future paper.

There is so much that is still uncertain in regard to this sys
that I have thought best to put on record the following obse
tions. I do not, however, wish to express an opinion a
whether they represent actual physical phenomena, or whe
they were merely optical illusions. Upon January 13 the
satellite appeared distinctly shortened equatorially when a
minimum phase. The appearance lasted for thirty-four min
and when first noted the seeing was fairly good, being ma
3.5, but later became worse. This phenomena has never
noted before nor since, although upon one night it was tho
that a slight polar flattening had been detected. In our ea
observations the 2d satellite not infrequently appeared long
the 1st. In all of our more recent observations it has appe
round at the maximum phase, like the two outer satellites.
some of its minima the 3d satellite retains the elliptical phas
a longer time than at others. Thus it remained short for t
days in succession upon January 13, 14, and 15. Usually

oes not last more than one day or two at the most, de- upon the hour at what the elliptical phase takes place.

bservation of December 11, described in my first paper, has nfirmed, and shown to indicate a genuine phenomenon. observation the position angle of the elongation of the ne 2d satellite was shown to suddenly shift through thirty just before contact with the limb of the planet, prior to ion, the satellite taking a position parallel to the limb. ange was ascribed to the action of a Jovian atmosphere. change was quite unexpected when it was observed it desirable to repeat the observation if possible at the first le opportunity. Such an opportunity occurred upon Jan- , when the satellite emerged from behind the dark limb planet. When first seen the satellite's disc was already covered, and the limb of Jupiter was indented by a deep t that point, presumably due to contrast with the bright the satellite. As soon as the emersion was complete, it n that the satellite was flattened parallel to the limb of et. A few minutes later the position angle of the flatten- ed to its usual position, perpendicular to its orbit, just rred in the former observation. Upon January 1 the 1st was watched as it approached the limb previous to ng. No flattening whatever was noted, however, nor did nge of shape occur at the moment of contact. A similar tion was made upon January 26, when it emerged from of the planet. These observations indicate that the noted in the 2d satellite is not an optical illusion, and flattening and change of position angle occur only e satellite is beyond the planet.

appearance of the 3d satellite upon January 27 from be- dark limb was a more interesting observation, and must ibed at length. The first contact occurred at $6^{h}\ 06^{m}$ A. M. the second could not be observed advantageously. The angle of disappearance was almost exactly forty-five de- om Jupiter's equator. At $8^{h}31^{m}$ I began looking for the rance, ahd at the end of a minute and a half a faint hazy as seen projecting beyond the terminator of Jupiter. This brightened. and in one minute more the edge of the the satellite made its appearance, a dark narrow band ing it from the terminator. This band was estimated to in breadth, and subsequent computation showed that its must have been $0''.16$ if there was no appreciable twi- used by Jupiter's atmosphere. The successive appearances observed are indicated in the drawings, which are construct on a scale of one centimeter to the second of arc. As a power 700 diameters was employed in the observation the proper effe will be obtained if these drawings are viewed from a distance



ten feet. The round body represents t satellite, and the lo one a portion of t terminator of Jupite The diameter of Jupit would be about fou teen inches. Since t interval between t third and fourth co tacts was of ten mi utes' duration the was ample time to o serve the dark ban and estimate i breadth, comparing it with the known breadth of the micro ter threads. By $8^h\ 41^m$ the satellite was more than half unco ered, and it was noted that the cusps were distinctly rounde as is the case with the Sun, when near the horizon, as seen fro a high mountain peak. No notch whatever was seen in t terminator as had been the case with the 2d satellite.

This was undoubtedly due to the less intrinsic brilliancy of t 3d. From its distorted shape it was impossible to tell exact when the fourth contact occurred. At $8^h\ 46^m.5$ it was not that the dark band had broadened to $0''.5$ in breadth, but $8^h\ 48^m$ the satellite was recorded as still flattened slightly. Tw minutes later it was perfectly round. At $8^h\ 51^m.5$ it was sep rated from the terminator by its own diameter and it w recorded that the satellite was but little brighter than the ter nator. The interval between the first and the third contacts w $2^h\ 27^m.5$. The geocentric duration of the occultation is given the almanac as $2^h\ 29^m$.

The first conclusion to be drawn from these observations that Jupiter is not self luminous, but is only visible when it illuminated by sunlight. The second conclusion is that it surrounded by a rare atmosphere outside of its cloud su face, which is capable of producing a measurable refractio This refraction has been computed, employing the observatio at first and third contact, and these when the satellite was sepa

rom the terminator by 0″.5 and also by its own diameter.
ying the third of these observations as our standard of
rison, the refraction of Jupiter's atmosphere at its cloud
e amounts to 0″.59. Employing the fourth observation as
andard the refraction appears to be 0″.38. The third ob-
ion was probably the more accurate, but was partially
d since the satellite was not yet free of the planet's atmos-
which is still sufficiently dense to produce an appreciable
at an altitude of 0″.8 or 1900 miles above the planet's
If we take the atmospheric refraction at the cloud surface,
50 ± 0″.05 we shall probably be not far from the truth.
he atmosphere should rise to such a great height above the
's surface was perhaps to be expected from the gradual
ter of the absorption of the planet's light near the limb.
such a height should be reached in spite of the high gravita-
onstant in those regions is an independent indication of a
temperature at the planet's surface, and a comparatively
mperature at an altitude of 1900 miles above it. The faint
seen beyond the dark limb of the planet for about a minute
the satellite made its appearance was doubtless analogous
e same phenomenen seen preceding the rising of our own
and may have been caused also in part by the illumination
uds in the planet's atmosphere too small to be separately
.

QUIPA, Peru, February 18, 1893.

THE PERIOD OF Σ 1785.*

S. W. BURNHAM.

paper on the binary star, Σ 1785, printed in *Monthly No-*
R. A. S. for December, 1892, I have given a complete list of
icrometrical measures of this pair from the first observa-
of South in 1823 to the last measures in 1892, made with
-inch at Mt. Hamilton; and also a diagram drawn to scale,
ng the relative positions of the components at these vari-
pochs. The arc of the apparent orbit passed over during
xty years covered by the observations is about 84°. Some
e early measures are very discordant in distance, and so
usly erroneous that it is necessary to reject them alto-
r in making any investigation of the real orbit. The object

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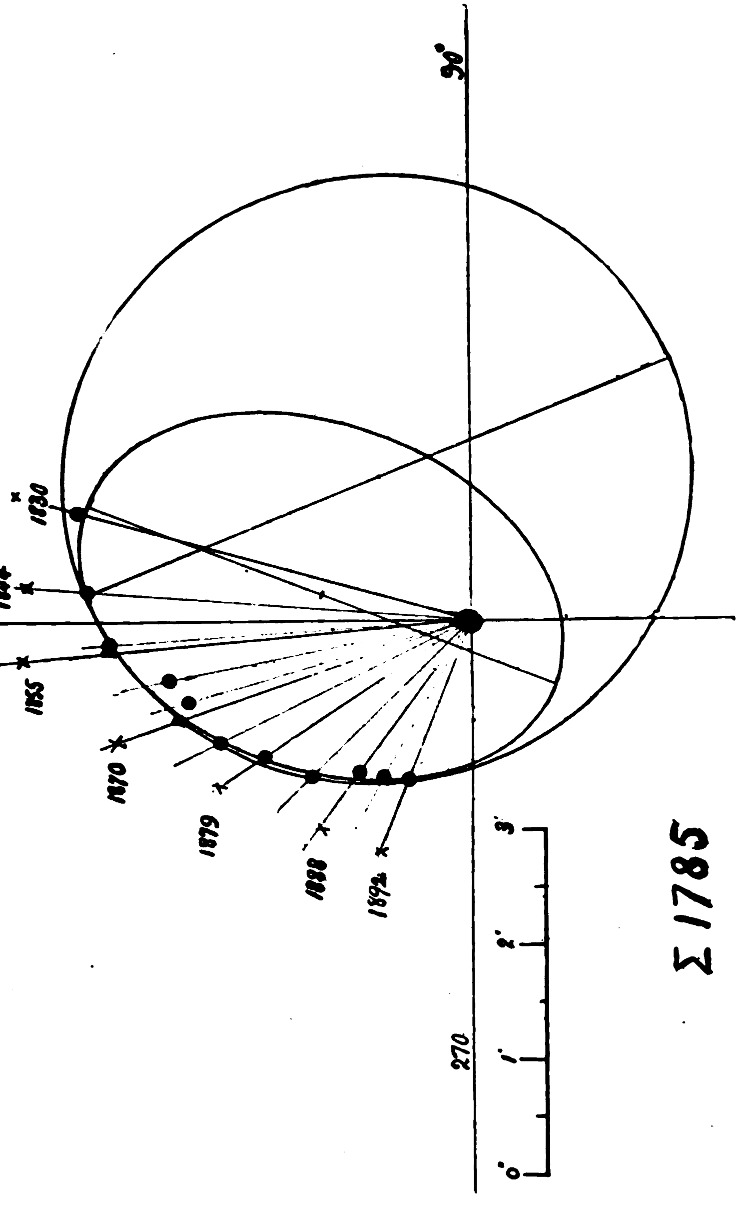
ommunicated by the author.

in collecting these measures was to furnish data for a careful vestigation by those who give their attention specially to t department of theoretical astronomy; and I had supposed th the facts were now sufficient to obtain a fairly approxim period.

I have recently examined these measures more carefully with view of ascertaining the periodic time, or within what limits it likely to be. I have used, as heretofore, the graphical meth This, for preliminary investigations at least, seems to possess a vantages over any other in placing before the eye at a glance t entire case, and showing at once the result of any propos change in the apparent ellipse. Where this is not so readily se one is apt to be misled by an apparently satisfactory agreeme between the observed and calculated positions, and to conclu that the result must be the best that is obtainable from the giv measures.

The accompanying diagram gives the results of this examin tion. I have used selected mean results at convenient interva as shown, which are laid down accurately to scale. The smal ellipse was then drawn to satisfy equal areas in equal times accurately as possible. This ellipse gives a period of about 1 years, and an eccentricity of the real ellipse of 0.63, with peria tron passage in 1906. It was apparent that with the length arc discribed, many other and much larger ellipses could be drav which would equally well satisfy the observations, and, so far one can tell at this time, give periods as likely to be correct. T larger ellipse was then drawn, and it represents the measu throughout exactly as well as the other. There is no apprecia difference between them in this regard except as to the measu of Struve in 1830, and the difference there is only 0″.11. T is not only an insensible quantity in such a distance, but below the probable error of his measures. In fact his measu of this pair range in distance from 3″.32 to 3″.57, the mean bei 3″.487. If any weight were to be given to the other measures that time, South 5″.66 (1823.40), Herschel 4″.62 (1830.20) a Herschel 7″.69 (1831.34), the distance of the companion as gi by the larger ellipse is still much too small, consequently ellipse itself. These other measures, however, should not be u for any purpose, and it is far better to rely wholly on the obs ations of Struve.

The second ellipse gives a period of a little over 300 years. T eccentricity of the real ellipse of which this is a projection is 0. differing in that respect but little from the other. It is proba



Σ 1785

that the first ellipse could have been made a little smaller, so that
appears to be safe to say that the period of this pair is somewhe
between 120 and 300 years, and that until a longer arc has be
passed over, it will be impossible to say with any certain
what the real time is. For the next ten years the two ellipses a
practically coincident, and the measures will not show the exte
of the apparent orbit, but the observations of the suceedi
decade should be sufficient to confine the error of the periodic ti
within narrow limits. This will always be an easy pair to mea
ure, for with the shortest time the minimum distance will not
less than 0″.6 and may be as much as 1″.

THE BALANCE ROOF FOR TELESCOPE BUILDINGS.*

CHARLES A. POST.

In the March issue of ASTRONOMY AND ASTRO-PHYSCS I notice
article ay Mr. A. E. Douglass, entitled "The Balance Roof for T
escope Buildings," in which the writer describes a form of roof f
telescope sheds adopted at the Boyden Station, Peru, which
thinks will be useful to eclipse expeditions and also to the owne
of small telescopes.

In a matter of this kind any question of priority of invention
of little moment, but as the article substantially describes a som
what larger structure built, and as far as I know, invented
me, during the winter of 1890–1891, perhaps my three years' e
perience may also be of interest to your readers. I inclose a nu
ber of photographs which were taken during the winter of 189
1892, and of which copies have been quite widely circulat
among my friends. These photographs were shown, and e
plained by me, at a meeting of the New York Academy of Scienc
during that winter, a report of which appears in their transa
tions.

It will be noticed that my house differs from the one describ
by Mr. Douglass only in the point of size and in the fact that t
roof opens in four sections, instead of two.

Its dimensions are 20 × 16 feet. This gives me room for a tw
inch transit, a sidereal clock, and a dark room for photograph
besides affording ample space for a six-inch equatorial.

Referring to the photographs,† No. 1 shows the Observato
closed. A A A are boxes filled with sand, which counterpoi

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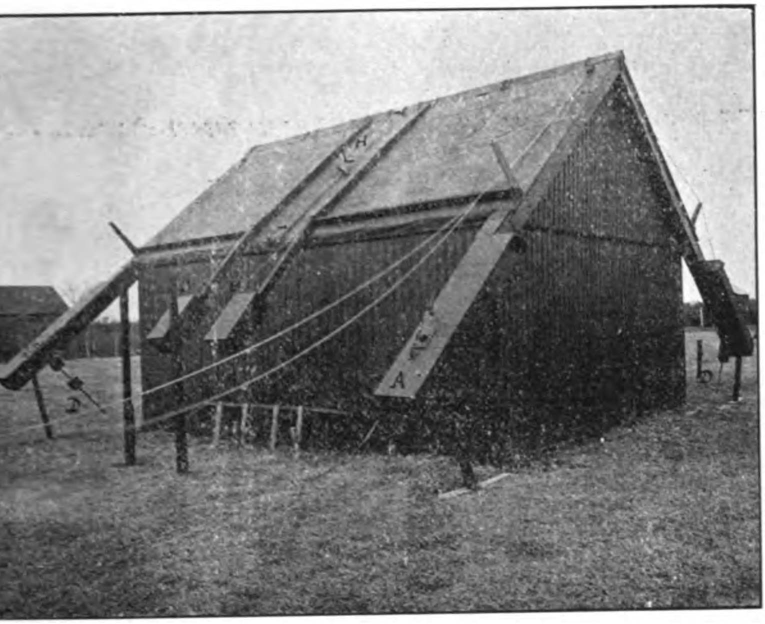
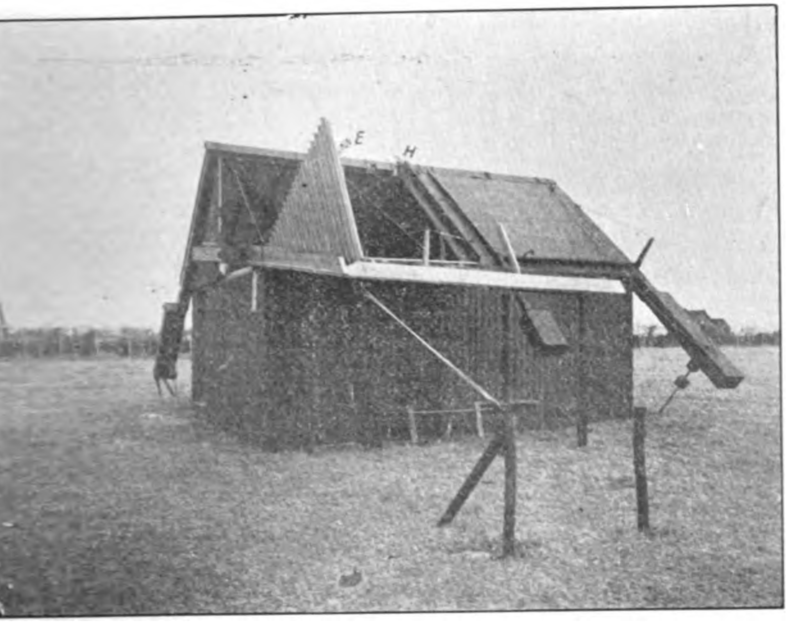
* Communicated by the author.

† Plates XXIII and XXIV following.

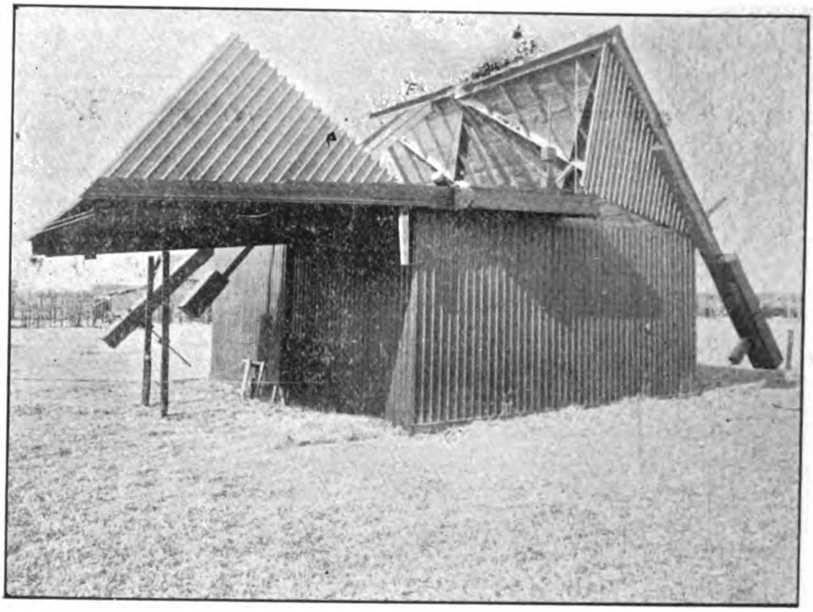
PLATE XXIII.



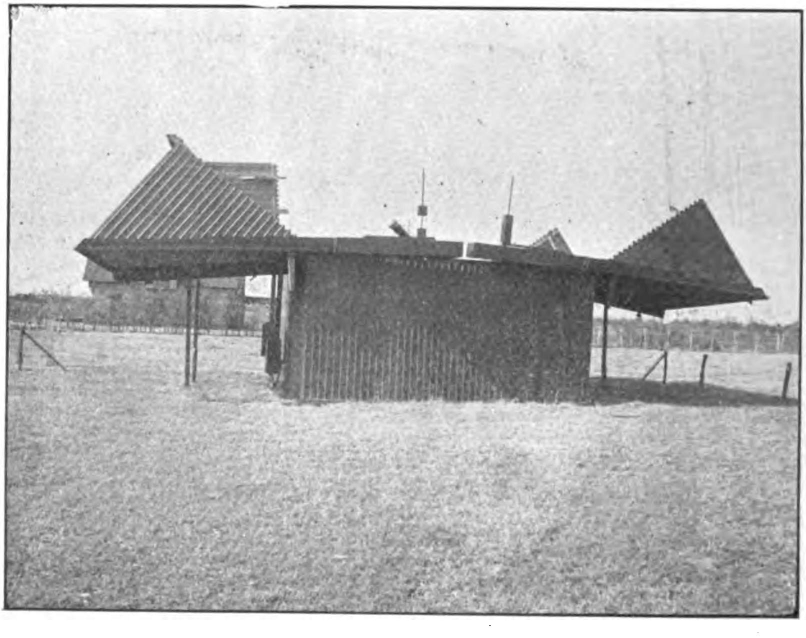
Photograph No. 1.



Photograph No. 2.



Photograph No. 3.



Photograph No. 4.

weight of the roof. B B B are rods, hinged at the eves, also
rying boxes filled with sand. The use of these weights is "to
vent the severe strain which a roof of such a size would suffer
en lifted by one end only." The strain is further taken up by
e rope braces shown in photograph No. 2, marked C. These
ces may be set up by screw turnbuckles. D D D are iron rods
right angles to the counterpiose boxes on each of which
es an iron weight, which is held in any desired position by a
screw. The object of these weights is so to adjust the centers
ravity of each section that when an inside clutch, marked E,
tograph No. 2, is released the section will assume the position
and G, photograph No. 3,—from which point it is hauled
n by a cord, leading inside of the building. When this cord is
ased, the section at once assumes the position F again, when
ight pull on another cord causes the roof to close and the
ch to engage.

he house may be used with any one of the four sections open,
others being closed as in photograph No. 2.

he material of the roof is half-inch pine, covered with heavy
vas painted. The canvas comes down over the eves and is
ened to the side of the house over the hinges.

lip of zinc, attached on one side only, and bent to the pitch of
roof, covers the joint at the ridge, and two small shutters
ked H, photograph No. 2, also worked from the inside, cover
opening between the sections.

ne building is absolutely weather-tight, and has admirably
ected the instruments during two winters. I have also in
a small corrugated iron dome, 12 feet in diameter. In this
snow is sometimes troublesome, but it never finds its way in-
he structure under discussion.

ne beauty of the edifice is perhaps doubtful, but its cheapness
utility are beyond dispute. The cost of the present building
about $275, while I am imformed that a dome of similar size
ld cost over $2,000.

is handled with great ease. In fact a child could open and
it unless the wind was very high, when some strength would
quired. The protection to the observer is nearly as good as
of a dome, while the extended view of the sky and the free-
from heated currents of air are decided advantages.

YPORT, March 13th, 1893.

ORBIT OF THE BINARY STAR β 416, SCORPII 185.[*]

PROFESSOR S. GLASENAPP.

In ASTRONOMY AND ASTRO-PHYSICS for December 1891, P fessor S. W. Burnham has called the attention of astronomers a new binary star, β 416, discovered by him in 1876. Althou there were given seven positions of the components, they w grouped in such a manner that they were insufficient for the termination of the exact orbit. Last year Professor Burnh measured this star on four nights, and has kindly communicat to me the results of his observations.

The following is a list of the measures of this system:

t	θ	S	Mag.	*n*	
1876.52	240° ±	1″.8 ±	6.0—8.5	1	Burnham
77.53	222 .6	1 .80	7.0—8.5	1	Cincinnati
77.64	224 .4	1 .77	7 —9	1	Russell
88.72	147 .5	1 .89	6.0—7.5	1	Burnham
89.47	134 .1	1 .35	6.4—7.5	3	Burnham
89.63	131 .9	0 .97	6 —8.5	1	Pollock
91.53	82 .3	0 .51	6.9—7.6	3	Burnham
92.38	24 .4	0 .58		4	Burnham

We take the simple arithmetical means of the measures ma in 1877 and 1889, and thus obtain six mean places:

1876.52	240° ±	1″.8 ±
1877.58	223 .5	1 .78
1888.72	147 .5	1 .89
1889.55	133 .0	1 .16
1891.53	82 .3	0 .51
1892.38	24 .4	0 .58

From these observations we derive the following elements:

$T = 1892.00$
$\mu = 34.85$ years.
$\eta = -10^\circ.3293$
$\Omega = 104^\circ.3$
$\lambda = 300^\circ.7$
$i = 45^\circ.4$
$e = 0.65$
$a = 1''.52$

These elements represent fairly well all the observations exce the first which was only an estimate of the angle and distance the time the pair was discovered in 1876 with the 6-inch refract (See Seventh Catalogue of New Double Stars, *Am. Jour. S* Sept. 1876; and ASTRONOMY AND ASTRO-PHYSICS, X, 489).

The comparison of the observed and calculated positions w be found in the following table:

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[*] Communicated by the author.

	θ_o	θ_c	$\theta_o - \theta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$
.52	240° ±	228°.0	+ 12°.0 ±	1″.8 ±	1″.90	− 0″.1 ±
.58	223 .5	224 .1	− 0 .6	1 .78	1 .84	− 0 .06
.72	147 .5	146 .8	+ 0 .7	1 .89	0 .96	(+ 0 .93)
.55	133 .0	134 .1	− 1 .1	1 .16	0 .87	+ 0 .29
.53	82 .3	81 .7	+ 0 .6	0 .51	0 .52	− 0 .01
.38	24 .4	24 .0	+ 0 .4	0 .58	0 .39	+ 0 .19

he observed distance in 1888 seems to be too large, and, being
a single observation, I have omitted it in determining the
or axis of the real ellipse.

is to be regretted that in the interval between 1877 and
8 there are no observations. During this time the satellite
ribed an arc of 76°, and a single observation in the middle of
t interval would furnish the data for obtaining a very exact
it.

his star has a rapid motion, and it is very desirable that
onomers possessing large telescopes should observe it each
r. For this purpose I have made the following ephemeris:

Ephemeries of β 416.

t	θ	ρ
1893.44	322°.1	0″.63
1894.44	300 .4	0 .93
1895.44	289 .0	1 .19
1896.44	281 .4	1 .39
1897.44	275 .6	1 .56
1898.44	270 .7	1 .69
1899.44	266 .6	1 .80

servations of the current year, and of 1894 will be of great
e for the study of the orbit. I should be very glad to secure
measures made this year, and will endeavor to ascertain the
ections of the elements.

e place of this star for 1880 is:

$$\text{R. A.} = 17^h\ 10^m\ 47^s$$
$$\text{Decl.} = -34°\ 51'.2$$

ASTUMAN, Gov't. Tiflis, Russia,
March 1, 1893.

TE.—Since sending the elements of the orbit of β 416 to the
ors of ASTRONOMY AND ASTRO-PHYSICS, I have received No.
of the *Astronomische Nachrichten*, which contains measures
ouble stars at the Sydney Observatory. Among these observ-
ns are the following measures of β 416 by Mr. Sellors:

1890.600	123°.3	0″.81	7 − 9
.608	120 .6	0 .82	
1890.60	121 .95	0 .81	

I have compared the elements given above with this positior and have obtained:

$$\begin{array}{rr} \theta_c = 113^\circ.0 & \rho_c = 0''.72 \\ \theta_o = 122\ .0 & \rho_o = 0\ .81 \\ \hline \theta_o - \theta_c = +\ 9^\circ.0 & \rho_o - \rho_c = +\ 0''.09 \end{array}$$

We could use these observations for determining the correction of the elements, as the difference of 9° is not excessive in so sma a distance, but it will be better to do this from new observation made during the current year. Such measures will be of grea value because the radius vector will describe an arc of 60° sinc the last position in 1892.

THE PERIOD OF 20 PERSEI (β 524).*

S. W. BURNHAM.

The duplicity of 20 Persei was discovered at Chicago with th 18½-inch refractor of the Dearborn Observatory on February 1878. It was an extremely close and difficult object for that in strument, but I succeeded in getting a fairly good set of measur in that year, and again in 1880. With the exception of a sing observation at Madison in 1881, I had no opportunity to mea ure it again until I resumed double-star work at Mt. Hamilto It would follow almost as a matter of course that so close a pa would be found to be in rapid motion. All of the most interes ing binaries, and these have periods of less than twenty-fi years, belong without exception to this class. The notable e amples are, κ Pegasi (β 989), δ Equulei (OΣ 535), 85 Pega (β 733), ζ Sagittarii (Winlock), β 883, and perhaps β Delphi (β 151), 9 Argus (β 101), and β 416, and certainly many oth β pairs whose orbits cannot yet be computed.

The accompanying diagram is made as a preliminary investig tion of the probable period of this pair. The measures are too fe to give anything more than an approximate value, and it will at least some years before additional data can be obtaine At all times it will require a large aperture, and an experienc observer to get reliable measures. A pair of this kind is a seve test in both directions..

The following are all the available observations:

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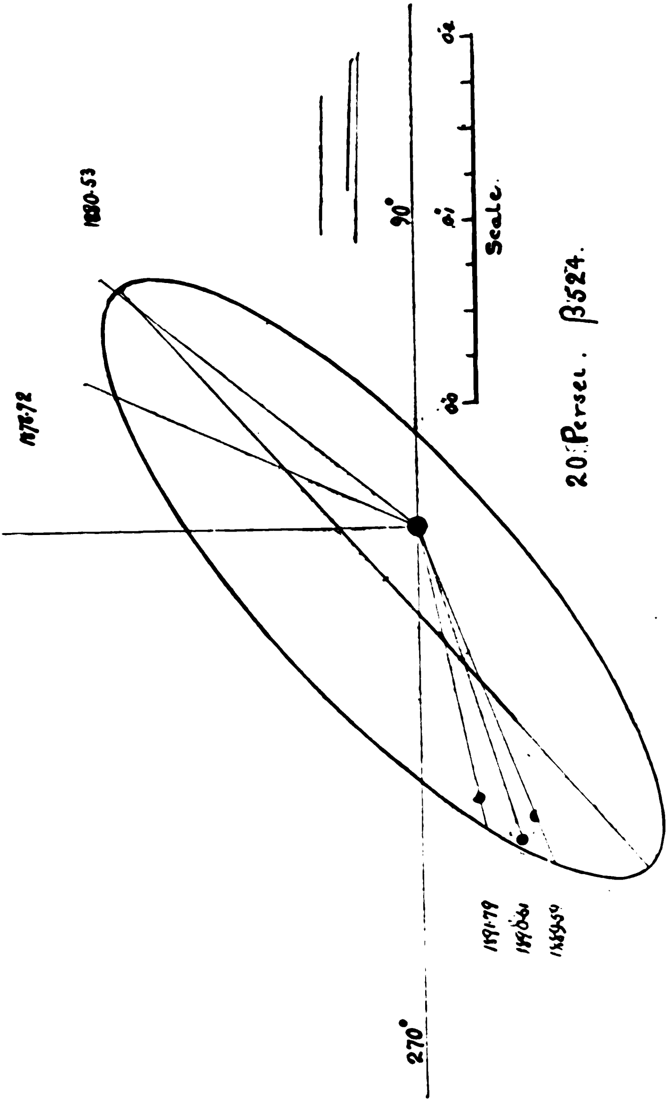
* Communicated by the author.



20 Persei. β 524.

1878.72	156°.0	"less than 0″.25"	β 4n
1880.53	141 .4	0 .22	β 3n
1889.59	291 .3	0 .17	β 1n
1890.61	287 .6	0 .18	β 3n
1891.79	281 .7	0 .15	β 3n

These measures were all made with the 18½-inch Chicago refractor, and the 36-inch refractor at Mt. Hamilton. The mean of the first two sets differ slightly from those given at the tim the measures were first published, since I have combined m measure of 1878.909 with the first set, in place of the second, a was done originally when the rapid change in the angle was no fully considered. I have also rejected two single measures wit inferior instruments, and the observations of Engelmann in 188 which are certainly erroneous in angle. His instrument wa much too small to do anything with a pair of this kind, notwithstanding his skill as a double-star observer.

The mean of the distance measures in 1878 is 0″.32, but expressly stated at the time the observations were published tha this was too large, and that the real distance was probably les than 0″.25. There is little doubt, when the subsequent measure are considered, of this being the fact, and that 0″.20 would b more nearly correct. The latter value has been used on the diagram. The measures as a whole are very consistent, and apparently accurate, when the extreme difficulty of this pair is take into account. The largest telescope in the world is none too powerful to properly measure it under the best conditions. Th approximate corrections to these measures to make them conform to the apparent orbit shown on the diagram are as follows

1878.72	153°.8	0″.19
1880.53	142 .5	0 .21
1889.59	294 .0	0 .20
1891.79	279 .5	0 .16

The differences are trifling when compared with the unavoidable and ordinary errors of observation in so close a pair.

This ellipse gives a period of 20.7 years, eccentricity 0.50, an periastron passage in 1883.8. The minimum distance would b but little more than 0″.03, and of course no telescope in existenc could possibly show any elongation. It will be a number o years and perhaps a good many, before it will be measured agai but I trust the time will come when some one of the large telescopes of the future will be devoted to the study and measurement of these remarkable systems.

s a wide double star, 20 Persei has been known since the time
Sir William Herchel who measured it in 1783 (= H III. 60).
s also entered in the catalogue of Sir James South (= S 420),
l later went into the *Mensura Micrometricæ* as Σ 318. This
npanion is much too distant to make any physical relation in
least probable. As a matter of fact, the two stars have been
tively fixed from the first, as will be seen from the following.

1783.58	239°.5	14″.03	H 1n
1829.14	236 .8	14 .08	Σ 2n
1890.61	237 .2	14 .08	β 3n

here are many other measures of this star, but these are suf-
ent to show that it is devoid of interest so far as motion is
cerned.

THE FORMATION OF RINGS AS A PROCESS OF DISINTEGRATION.*

DR. M. WILHELM MEYER.

n an earlier article on the fifth satellite of Jupiter, on page 142
of this volume (*Urania*, 1893) it has already been shown
t on the surface of the very small satellite which revolves in
neighborhood of the most powerful center of attraction after
sun, there is a very singular contest between the attractive
es, which on the one side tend to draw a free body to the cen-
of the moon itself, and on the other to draw it to Jupiter. I
ne, indeed, to the conclusion that the force operating in the
ction of Jupiter must certainly be the predominant one.
e this result opens a very interesting cosmological question
which I shall come immediately) it will be of importance first
show how far the above conclusion is hypothetical.

n respect to this I will take the liberty of referring to my ar-
e "A Demonstration of the System of tne Universe," which ap-
red in the first annual volume of this Journal.† In this it was
wn, even to those who know nothing of mathematics, that
is theoretically able to determine with absolute certainty the
raction which is exerted upon any given heavenly body of our
netary system, providing the same has another revolving
ut it. This revolution is a direct result of the attractive force

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Communicated by the author in German and translated by Miss G. M. Pot-
of Carleton College.

Urania.

of the central body which, as has been demonstrated, in the e tire solar system decreases with the square of the distance fro the center. At the same time this effect of gravity is directly d pendent upon the mass of the body. When one, by observatio finds in a certain case that a satellite falls toward its plane faster than a body at the same distance would fall to the eart it proves that the mass of the planet is proportionately great than that of the Earth.

Now since Jupiter possesses, besides the new moon, four pr viously known satellites whose motions have been quite exact studied, one can compute with all certainty, not only what at tractive power Jupiter exercises upon a body at its surface, bu also at any given distance. If we find therefore that at the dis tance of the first—*i. e.*, the new satellite of Jupiter—a body woul fall 1.96 m toward Jupiter in the first second, this is determine with certainty.* Now let us transport ourselves to the surface the new satellite and imagine Jupiter standing exactly overhea Every object on the surface will have the impulse in the firs second to rush through the above specified distance towar Jupiter; for Jupiter, one would call it a falling motion, for th satellite, it is an upward motion.

The question now arises whether the attraction of the principa planet is greater than that which the mass of the satellite exert upon an object at its surface. We must make hypothetical suppo sitions as to the density of the mass of which the moon is formed and at the same time also as to its size, *i. e.*, its diameter. No as far as the density is concerned the effects of attraction whi the remaining satellites of Jupiter exercise upon each other hav shown that the satellites are less dense than Jupiter itself. No as is well known, Jupiter consists of a mass four times less dens than our Earth; this again is on an average much less dense tha many of the heavy substances which appear upon it; for instanc the density of platinum is about four times that of th Earth. Platinum is the densest, the heaviest of all know substances; should the Earth consist of platinum our Moo would necessarily be impelled to fall four times faster toward i No heavenly body, as far as has been determined, possesses great a density. Should we assume, nevertheless, that the ne satellite of Jupiter posseses the density of platinum, we woul give, in all probability, the highest possible maximum limit to it manifestation of power. Under this assumption, however,

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* Later observations by Barnard have given other values for the distance a time of revolution of the new heavenly body, from those first made known a used here. One may rather abide by the old values for the present since the ne ones are not yet to be regarded definitive.

alculate quite exactly how large the new heavenly body be in order that an object upon its surface shall be drawn s strongly toward its center as by Jupiter, so that it will be ly without weight when the principal planet stands in its . It results, that to accomplish this, that the new satellite have a diameter of 1300 km. The real size of this satellite is, sure, not directly measurable. It appears, as is known, as small point of light without diameter which, as it seems, hitherto be made visible in only two telescopes,* of which s is well known, is the largest in the world. But again it e calculated with certainty, that a heavenly body with a ter of 1300 km. at the distance of Jupiter must have a ter of nearly half a second of arc, which would necessarily ible in our good telescopes of modern times.

e this is not the case, it is to be concluded with certainty freely movable object on the surface of the new moon must diately fly away from it toward Jupiter as soon as the lat- es above the horizon. True, this inference is hypothetical, could only be overthrown if the satellite consisted of a denser mass than we have ever become acquainted with on rth or in the whole wide universe. The probabilities are ore many thousand to one, that the new satellite is not o hold freely movable objects upon its surface.

noteworthy that similar circumstances, although, for the part, not so remarkable ones, exist in cases of all satellites are to be found specially near their planets. Both satellites rs, the first of the old satellites of Jupiter, the first three of tellites of Saturn, the first two of the satellites of Uranus l in the same situation, at least upon the supposition that ass of the satellites is not denser than that of their plan- The following table will show this:

	g. In metres.	Δ	D. Computed km.	D. Obs.
s	0.242	Density of Mars	2550	8.3
	0.049	Densify of Mars	409	7.2
lites of Jupiter	1.96	Density of Jupiter	20600	.....
lites of Jupiter	1.96	Density of Platinum	1300	.....
ites of Jupiter	0.354	0.52 Density of Jupiter	7170	3814
llite of Jupiter	0.140	Density of Jupiter	1475	3413
	0.549	Density of Saturn	12090	513
dus	0.333	Density of Saturn	7330	635
	0.217	Density of Saturn	4790	989
	0.132	Density of Saturn	2920	941
	0.068	Density ot Saturn	1500	1295
	0.080	Density of Uranus	1020	....
l	0.041	Density of Uranus	524	....
s	0.010	Density of Uranus	123	925
e of Neptune	0.027	Density of Neptune	229	3163

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elescopes above 18 inches aperture in America have seen this satellite. [Ed.

In this table *g* indicates the space through which a body at tl
distance of the satellite would fall towards the planet in one se
one of time.

Under Δ the assumed density of the satellite mass is given; tl
last two columns give the true diameters of the satellites cor
puted according to the assumption more exactly denoted abo
and those ascertained from photometrical and other measu
ments.

What will take place upon the surface of these satellites und
the above designated conditions? This may be followed up wi
certainty by computation. With the impulse of bodies, not held
the surface by molecular forces, to fly toward Jupiter, will be co
bined their motion in the orbit of the satellite; the bodies lea
the satellite and scatter themselves along the orbit forming a rin
whose diameter must be less than that of the satellite's orbit a
which must resemble in every respect the gauzy, transparent ri
which the bright ring of Saturn surrounds. If more and more o
jects come to it, dust, rock that has crumbled away from the sat
lite, then the ring will become ever denser and finally resemble t
bright rings of Saturn. At the outer edge of this ring, the ori
inal satellite will continue to revolve and feed the ring with t
objects which have deserted it, It can be easily shown that the
will never cease to be such loose objects upon the surface of a
given, solid body which revolves around another in our sol
system. As long as it is surrounded by water and air, whic
however, is no longer possible at this stage, the operation of t
atmosphere and moisture produces disintegration. When this
longer operates the alternations between the solar rays and t
piercing cold of space, acting all the more powerfully because
the absence of the atmosphere, would by the expansion and co
traction of the surface produce fissures, such as already cover o
Moon's surface by thousands, and finally large masses of sto
which are surrounded on every side by such fissures will be oblig
to break loose. This processs of crumbling to pieces, workin
very slowly to be sure, but incessantly, will constantly rea
deeper strata as soon as the upper ones are loosened and all fra
ments are dispersed over the ring. We can therefore mainta
to-day, many thousand to one, *that the fifth satellite of Jupit
began long ago to form such a ring and thus Jupiter possesses
the present time just as Saturn does, a ring at the distance of th
satellite.*

Probably, however, the same has too faint a light to ever
perceived. Nevertheless it would not be useless for the astron

s who are equipped with the best telescopes to make observa-
s in this direction. The same is true with respect to the other
llites, and with respect to those of the other systems, which
e been already mentioned.

rough the preceding considerations it has been possible to
a new object to the ever widening field of the astronomy of
invisible. It seems furthermore hardly doubtful that the rings
aturn are the product of the disintegration of several original
llites. This is also indicated by the fact that the profile of
rings extends outward in somewhat pear-shaped form. The
est conglomeration of fragments must indeed be found at the
ide according to our observations; at any rate it can be
vn that a spherical heap of loose fragments revolving at the
ified distance would necessarily form these Saturn rings, even
ll the details of their appearance. The rings of Saturn are
therefore, in all probability, to be regarded as a formative
e of a spherical body, which has remained stationary from
et unknown causes, as has formerly been believed, but are
er to be regarded as a product of the destruction of such a
.

we assume the Kant-Laplace hypothesis of the origin of
lds to be a fact then it can be concluded from the mere exist-
of the fifth satellite of Jupiter at the observed distance, that
s approached the planet by a considerable distance since it
ng into existence. That is to say it is impossible with the
lominating gravity of the planet and at this distance, that
e should take place a condensation of the matter of the orig-
ring into a satellite which is not able to retain its surface
ions through its own power.

ere exist as is well known still some other reasons which
e a gradual approach of the secondary bodies toward the
e of their system highly probable. There is especially the
or-dust which, ever present in space, opposing a constant re-
nce to the motions of the heavenly bodies, compels them to
slowly toward the attracting centre. If this assumption is
one sees how this most invisible and volatile agent in the
erse forms one of the principal factors for the disintegration
destruction of the heavenly bodies. It leads the bodies, in
irst place, up to that limit at which the attractive power of
lanet begins to loosen parts of its surface. Here destructive
ity sets in, and in most cases long before the satellite could
fallen upon its planet the dissolution of the satellite into the
will have become complete. Then, the meteor dust, which

was the cause of this interception and consequently also of th fatal fall, at the same time guards the planet from the terrible c tastrophe of the precipitation of the satellite mass as a who The satellite mass only falls back upon the mother body in t course of many thousands of years and in the form of quite ti fragments, falling stars and meteors. Our moon upon which body falls 0.829 m. in the first second, would begin to dissol into a ring at the distance of 2.43 Earth's radii from the Eartl centre. It is not impossible that the brightness of the zodiac lights proceeds from a ring of small meteors which are the pr duct of destruction of a former satellite of the Earth.

Finally the noteworthy fact may be referred to, that all those satellites of our planetary system which are in all prob bility already inside the zone in which the disintegrating activi of gravity begins, are remarkably small, from which fact it is be supposed that the disintegration is already considerably a vanced. The only exception to this is the hitherto so-call first satellite of Jupiter, although it is the smallest among t four old satellites. It is, however, doubtful whether the assum density, equal to half that of Jupiter, corresponds to the realit should it be once again as dense, thus equaling the density of J piter, the satellite is found yet outside the destructive zone.

The craters of our Moon also give a support to the correctne of the view here presented. That is to say, if the satellites real disintegrate into dust rings and from these gradually precipita fragments upon the solid surface of the planet, then formati would arise from the deposited matter which, as experimen prove, would bear a striking resemblance to the craters of t Moon. The objection is done away with which has been rais against the old meteoritic hypotheses, as to the formations of Moon's craters, that the great number of the specified formatio on our satellite can hardly proceed from those sporadic mete ites, as they occasionally meet our Earth. Such ring meteorit can, and must, in most cases appear in masses and produce wh showers, as certain districts of the Moon's surface seem to sho Since Dr. Gilbert of Washington quite recently expressed a ve similar opinion as to the origin of the Moon's craters (Public tions of the Astronomical Society of the Pacific, vol. IV., No. 2 I will take the liberty of referring to the fact, that, agreeing p fectly with this gentleman, I have already expressed this opini in my popular book "Die Königin des Tages," pp. 126 u. f. (T chen, 1885), and also in the articles "From the Earth to t Moon," which have repeatedly appeared in the *Urania*. (Sam lung populärer Schriften, published by the Urania Company, N 1, pp. 21 u. f).

THE EVOLUTION OF DOUBLE STARS.*

C. H. DARWIN.

The essay which we review is a dissertation for the doctorate of philosophy of Berlin, and the author, Mr. See, is an American, although he writes in German.

The component stars in double systems appear to be usually of comparable magnitudes, and are found to move in highly eccentric orbits. This case the author holds to be the normal one, whilst the solar system, with its one preponderant mass, and its nearly circular orbits, would be exceptional.

He attributes the observed high eccentricity of orbit to the influence of tidal friction, and accordingly the greater part of the paper is devoted to the consideration of the results which will ensue from the supposition that each of two bodies raises in the other tidal disturbances, which are subject to frictional resistance.

If the rotations of the two bodies differ in speed, the problem is an insoluble one, without some postulate as to the law of the frictional resistance. The author is, however, of opinion that sufficient insight may be gained from the solution in the case where two equal bodies rotate with equal speed. This opinion seems justifiable, but it might have been well if the dynamical stability of equality of rotations had been explicitly pointed out. That there is such stability is clear from the consideration that, if one of the bodies rotates more rapidly than the other, it is subjected to a more rapid retardation of rotation, and there is accordingly a tendency towards the restoration of equality.

The influence of tidal friction on the elements of the orbit of a satellite and on the rotation and obliquity of a planet have been investigated in my several papers, and Mr. See here adapts my conclusions to the case of the double tidal friction of two stars. The adaptation is not difficult, for whilst, the rate of change in the rotation of each star remains the same as though the other did not rotate, the rates of change of the elements of the orbit are exactly doubled.. Mr. See has than redrawn the curves which exhibit the gradual transformation of the system, and as might have been expected, finds them to have features closely similar to those of my curves.

The generality of these solutions is limited by the supposed

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* Die Entwickelung der Doppelstern-Systeme. Von. T. J. J. See. 60 pp. (Berlin: R. Friedländer und Sohn, 1893). From *Nature*, March 16, 1893.

smallness of the eccentricity and of the inclinations of the orbit and of the two equators to the plane of reference. The author, however, then passes to a second case, which is more special in that the equators of the stars remain coincident with the plane of the orbit, but which is more general in that the eccentricity is not treated as being necessarily small. The object is to obtain a numerical solution of the following problem:—Two equal stars, each of three times the Sun's mass, revolve in a nearly circular orbit at a distance equal to that of Neptune from the sun, and the rotation of each star is nearly equal to its orbital motion; it is required to find the greatest mean distance and the greatest eccentricity of orbit to which the system will change under the influence of tidal friction.

Mr. See solves this problem by methods analogous to those which I have employed, and finds that the mean distance will increase from 30 (Neptune's distance) to 50, and that the eccentricity will increase from an assumed initial value of one-tenth to a maximum of about three-fifths, which is attained a little earlier than the maximum of mean distance.

It may be remarked that these results can only be very rough approximations to the truth, because the calculation is conducted on the supposition that the moment of inertia of each star is the same as that of a homogeneous sphere of the same mass and radius, whereas it is obvious that the stars would really be highly condensed spheroids of great oblateness.

It is to be regretted that the calculation has not been repeated with variations of the assumed initial conditions. It is easy to see that a change in the assumed degree of concentration of the stars would give very different results. Supposing, for example, the stars had had only half the diameter assumed, the rotational moment of momentum would have had a quarter of its value in Mr. See's example. Now the enlargement of orbit is due to the transference of rotational to orbital moment of momentum, and thus the transferable moment of momentum would only have amounted to one quarter of its former value. But the orbital moment of momentum varies as the square root of the mean distance and hence the enlargement of the orbit could not have been so much as one-sixteenth of its former value. We may feel sure that the increase in the eccentricity of orbit would also have been largely reduced.

Notwitstanding this criticism, it appears to me that Mr. See fairly establishes the proposition that a high eccentricity is explicable by means of tidal friction.

Turning, then, to the question of the relative masses, of double-star systems, Mr. See remarks with justice that the comparable brightness of the components renders it highly probable that the masses are also comparable, and he sees in certain results of M. Poincaré and of my own an evolutionary explanation of this fact.

Jacobi first showed that an ellipsoid of homogeneous fluid with its three axes bearing to one another proper proportions, is a figure of equilibrium when it rotates about its smallest axes with a proper angular velocity. M. Poincaré next showed that if the length of the Jacobian ellipsoid exceeds the breadth in a certain ratio, the equilibrium becomes unstable, but that there is a stable figure which may be described as a Jacobian ellipsoid with a furrow nearly round the middle, so that it resembles an hour-glass with unequal bulbs. If we trace the further development of the hour-glass we find its neck gradually thinning, and finally rupturing, the figure of equilibrium, henceforth consists of two detached masses.

My own attack on this problem was from the opposite point of view, for I endeavoured to trace the coalescence of a pair of detached masses, so as to form an hour-glass or dumb-bell.

Mr. See reproduces the figures illustrative of both these investigations, and remarks that they both show that when there is gradual detachment from a rotating figure of equilibrium, the detached portion will not normally be a ring, but that there will ensue two quasi-spheroidal masses of matter of comparable magnitude. He also remarks that if the fluid be heterogeneous, the ratio of the masses will be much smaller than when it is homogeneous.

In the discussion of these figures of equilibrium the wording of the essay appears a little careless, for it might naturally be supposed to mean that increase of angular velocity is a necessary concomitant of the rupture of the neck of the hour-glass. Now it is a somewhat paradoxical fact that, with constant density, the longer elongated figures of equilibrium rotate more slowly than the shorter ones, and it might therefore seem that the rupture of the neck should go with retardation of angular velocity. But it is the value of the square of the angular velocity divided by the density which determines the length of the elongated figures, and thus increase of density tells in the same way as retardation of angular velocity. In the history of a nebula the only condition for rupture which can be specified is that of contraction.

The probability of this view of the genesis of double stars is strikingly illustrated by a number of drawings by Sir John

Herschel of various nebulæ. The great similarity between Herschel's nebulæ and the theoretical hour-glass is obvious. It may be hoped that in the book which Mr. See promises he will also illustrate this point by photographs.

Annulation is usually accepted as the mode of separation in the nebular hypothesis, but, as already stated, this is held by Mr. See to be exceptional. He thus regards the ring of Saturn as being exceptional in its history as it now is in appearance. Where he maintains that Saturn's ring will never coalesce into a satellite, he might with advantage have referred to the remarkable investigations of M. Roche,* who showed that a satellite would be torn to pieces by tidal action if it revolved at a distance of less than 2.44 times the planet's radius. We may here note the interesting fact that whilst Saturn's ring almost touches "Roche's limit" on the inside, the Martian satellite, Phobus, and the fifth satellite of Jupiter† almost touch it on the outside.‡

In order to prove his thesis as to the highness of the excentricity and the comparability of masses, Mr. See gives a careful table of the observed elements of the orbits and of the relative brightness of seventy-three pairs of double stars. The values of the elements are of course open to much uncertainty, but the mean eccentricity, which is found to be .45, must lie near the truth. In the few cases in which the masses have been determined, they are found to be comparable, and the comparability of the brightnesses confirms the generality of this law. Thus the facts of observation agree with our author's ideas.

Mr. See must be congratulated on having written an essay of great cosmogonical interest, and although his theory may never be susceptible of exact proof, yet there is sufficient probability of his correctness to inspire us with fresh interest in the observations of double stars.

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* "Acad. des Sciences de Montpelier," vol. i, (1847-50), p. 243. See also Darwin, *Harper's Magazine*, June, 1889.

† The values given by Barnard (*Nature*, p. 377) make the distance 112,000 miles, and Roche's limit 107,000 miles.

‡ It is proper to warn the reader that Roche's limit depends to some extent on the density of the planet. For the Sun it will be about one-tenth of the Earth's distance from the Sun. Thus a body of planetary size cannot move in a highly eccentric orbit, so that its perihelion distance is one-tenth, without being broken up into meteorites; and conversely a flight of meteorites with less than the same perihelion distance can never coalesce into a planet.

Astro-Physics.

NOTES ON SOME RECENT OBSERVATIONS OF NOVA AURIGÆ.*

W. W. CAMPBELL.

(*a*). On p. 56 of the current volume of ASTRONOMY AND ASTRO-PHYSICS Herr Von Gothard compares the intensities assigned by him and by myself to the lines in Nova Aurigæ's spectrum, and attributes the striking differences in our estimates to the different absorptive powers for violet rays of his instrument and mine. The true explanation is quite another one.

It has been pointed out (in A. AND A.-P. for November, p. 803) that the relative photographic brightness of lines in different parts of the spectrum cannot be obtained from my plates, since rays of only one wave-length enter the slit properly. Hence my estimates, quoted by Gothard, are *visual;* and, as stated in A. AND A.-P. for October, p. 716, the intensities of λ 4466 and λ 4336, which were not visible to me, "were estimated from the photograph by comparison with the line λ 4360." Herr Von Gothard's intensities are *photographic*, and based upon the curve of sensitiveness of an orthochromatic plate which would be shown by a photograph of the solar spectrum to be very peculiar.

On my plates, "by far the brightest line . . . is that at λ 4360. It is eight or ten times as intense as the Hγ line at λ 4336" [A. AND A.-P. for November, p. 820]. On Herr Von Gothard's plates these two lines are not separated, owing to the small dispersion used. They combine to form his line λ 434, "which is the most intense line of the entire spectrum," as the line λ 4360 is on my plates.

The curious curve of sensitiveness of his plates is shown by the absence from all his results of the lines λ 496 and λ 486, which we know to exist prominently in all the spectra photographed and in a region slightly actinic with ordinary plates; whereas λ 5750 in the yellow is successfully photographed, though it is no brighter visually than the blue line λ 486.

Herr Von Gothard has apparently taken the line λ 434 as the zero point for measurements of his plates. If on the Nova plate he assign to that line the wave-length 4360, the apparently erroneous position of Hδ (λ 4077) will be explained.

(*b*). I have re-measured the position of the yellow line, in connection with some work on the Wolf-Rayet stars, and have obtained for it:

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* Communicated by the author.

1893 Feb. 15, λ 5752, compared with mg λ 5712.
" 18, 5751, " " hg 5769.

(*c*). In the *Observatory* for January the Astronomer Royal for England called attention to a remarkable decrease in the brightness of Nova. It "was noted as invisible in the 10-inch finding telescope about Oct. 7th by Mr. Turner, Oct. 22d by Mr. Davidson and Oct. 25th by Miss Everett. This would imply that the Nova is below the 14th magnitude."

The Nova was observed by me visually with the four-inch finder on Oct. 12th, 19th and 22d, and spectroscopically with the grating on the 12th and 19th, and no significant decrease of brightness over that of August and September was detected. It was observed by Professor Barnard with the 36-inch on Oct. 21st, 23d and 25th; and in his opinion, since August the object has "as a whole remained essentially constant in its light." Estimates made at Oxford on Oct. 5th, 7th and 10th placed the magnitude at 9.5; on Oct. 19 at 9.7; on Oct. 25 at 9.8. It is impossible to harmonize the observations made here and at Oxford with those made at Greenwich on the same nights, unless, indeed, the Nova varied 4.5 magnitudes in a few hours. Such a variation must have great significance in any theory of the Nova, and it is unfortunate that we know so little of the light-curve on those nights.

(*d*). The following wave-lengths for the chief nebular line are additional to those already published:

Date.					λ	Velocity.
1892.	Dec. 13*	1st	order	grating	[5004.18]	[— 107 miles]
	" 14*	1st	"	"	[4.02]	[— 109]
	" 14*	2d	"	"	[4.22]	
	" 18*	1st	"	"	6.38	— 29
	" 18*	2d	"	"	6.16	
1893.	Feb. 10	1st	"	"	6.34	— 30
	" 10	2d	"	"	6.14	
	" 14	1st	"	"	5.90	— 33
	" 14	2d	"	"	6.41	
	" 27	1st	"	"	5.72	— 52
	" 27	2d	"	"	5.60	

Observations marked thus * were made by Mr. S. D. Townley in my absence from the Observatory. In his notes I find: for Dec. 13, "wind nearly 60 miles per hour," observations few and discordant; for Dec. 14, "wind 50 miles per hour," observations discordant; for Dec. 18, "very little wind," observations very accordant, spectroscopic adjustments tested next morning on Sun. The observations of Dec. 13 and 14 are entitled to very small weight. It is pretty certain that the wave-lengths were considerably larger in the interval of nearly two months when no observations were secured.

In any discussion of these observations it is necessary to take into account the difficulty of accurately locating the centre of a line so broad and diffuse as this one is. On two nights, in August and September, I suspected that the appearance of the line was changing, but was not able to confirm my suspicions [see A. AND A.-P. for October]. The error in the result for any night can scarcely exceed ten miles a second, and there can be no doubt of the reality of the change of wave-length. If it is due to orbital motion, a very unusual orbit would be required to satisfy the observations.

(*e*). Dr. Roberts' photographs of the region about Nova Aurigæ are certainly very interesting in that they show the probable non-existence of a *large* nebula, such as required in Dr. Seeliger's hypothesis. But to me it seems impossible that the 21″ or 13″ image of Nova should be seriously expected to prove anything concerning the 5″ nebula so easily visible in the 36-inch telescope, except that its light falls more largely in the non-actinic part of the spectrum than does that of the visually fainter star whose photo-images were 23″ and 16″ in diameter. I would suggest that the value of the evidence be tested by photographing in the same way some planetary nebula that resembles the Nova in magnitude and structure, as for example, N. G. C. 6790, and comparing the image of the nebula with that of a star slightly fainter [visually].

MT. HAMILTON, 1893, March 21.

ON THE ORIGIN OF SUN SPOTS.*

EGON VON OPPOLZER.

The question of the origin of Sun spots has not yet been satisfactorily solved; for every theory of Sun spots must be considered incomplete, unless it explains phenomena so intimately connected with the nature and origin of the spots, as are the periodicity and heliographic distribution of the spots. As, however, Young says in regard to the problem, this cannot be said of any of the theories thus far proposed; but every such theory must in addition be considered incomplete, unless it also makes plain the peculiar law of rotation of the Sun's latitudes, which goes hand in hand with the number and distribution of the spots. This discovery is due to Spoerer, but is too little taken account of in the

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* Translated from *Astronomische Nachrichten* No. 3416.

numerous theories of rotation. The result which Spoerer has derived from the discussion of spot observations (1861-71) is as follows:*

"The year 1866, which preceded the year of spot minimum, is remarkable from the fact, that at that time the usual angular rate of rotation almost entirely disappeared. . . . Any one who observes in a single year in which such circumstances exist, as in the year 1866, must consider it permissible to combine all the rotation angles into a mean value, . . . so that in the two years preceding the spot minimum the mean values of the angles of rotation give, with remarkable uniformity, nearly the same curve. . . . The evidence, that within the eleven-year period characteristic differences (before and after the minimum) present themselves in the annual curves of the mean values of the angles of rotation obtained for different latitudes completely excludes the idea, that there might be special periods of rotation for different zones on the Sun's surface; and we are led to attribute the periods of rotation obtained from spots to currents, which are at least as variable as the number of the spots and the distribution of the same."

This result, so important for astro-physics, is found again in the discussion of the succeeding periods, although not to quite so marked an extent. Unfortunately Dunér's observations of the rotation of the Sun† extend over a space of time of too small solar activity (3 years before the minimum) to further corroborate this phenomenon; but they seem to be favorable to it. When we consider the remarkably small probable error of Dunér's observations—they reach at the highest 0.03 km—I believe the following conclusions positively confirmed: Dunér forms for the velocities‡ of the individual zones the combined mean of the values for the years 1887, 1888, and 1889. If, now, we compare the means for the individual years with this combined mean, we obtain the following differences (mean combined mean):

SPOT ZONES.

φ	0.4	15.0	30.0	45.0	60.0	74.8
1887	+ 0.01	0.00	− 0.02	+ 0.02	+ 0.03	− 0.02
1888	− 0.08	− 0.08	− 0.03	− 0.03	+ 0.04	+ 0.05
1889	+ 0.07	+ 0.07	+ 0.06	0.00	0.00	− 0.02

We see immediately from this table, that the year 1887, which is furthest from the minimum year, coincided with the general

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* Spoerer, Publ. der Astr. Gesellsch. XIII, pp. 148-153; 1874.

† Dunér, Nov. acta reg. soc. Ups. Ser. III, Vol. XIV, 1891.

‡ In km per second.

mean; all the differences lie within the limit of error; the year 1888 shows large negative differences, *i. e.* smaller velocities, chiefly in the spot zone; correspondingly, in the year 1889, the year before the minimum, there were large positive differences, *i. e.* greater velocities, and these only in the spot zone; in the higher latitudes, on the other hand, the same circumstances prevail as existed in all latitudes in the year 1887, circumstances which tend to limit the velocities. Exactly the same appearances as those which the iron vapor at the surface of the Sun here shows with reference to its motion about the Sun, appear in the motions of the spots; also, if at the time of minimum the succession of spots begins in higher latitudes, other circumstances immediately arise there, and such as demand the ordinary rate of angular rotation, and this fact strikingly suggests how intimately the motion of rotation of the Sun's latitudes is related to the question of heliographic distribution, and gives us at the same time a clear indication as to where we must seek the cause of the rotation peculiar to the Sun, and wherein that cause consists, namely, in a limitation of the velocities.

After these preliminary explanations we will pass to a consideration of the character of the spots. The spots, and especially their nuclei, are masses of gas and vapor, which, by reason of their lower temperature, strongly absorb the light radiated by the photosphere. This shows itself in the spot spectrum, not merely by the strengthening and widening of many lines of the solar spectrum, but also by the appearance close to one another of countless lines, first discovered by Young* and later by Dunér,† which are not seen in the ordinary solar spectrum on account of their delicacy and faintness, and whose constancy of position leads us to conclude that the absorbing mass is very quiet, so that for this reason Dunér is inclined to prefer Secchi's to Faye's theory. That the spots are sunken, or, and this is enough for our question, may be sunken, into the photosphere may be considered a sufficiently established fact. Even Spoerer in his latest publication of Sunspot observations,‡ p. 427, is lead to assume this when he writes: "It must be assumed for these spots that the visible surface of the nucleus lay deeper than is the case on the average, unless in this and other cases we ascribe the deviations to errors of observation or to the configuration of the spot." If we combine all these results, we

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* Young, Amer. Jour. of Sci., Ser. III, Vol, XXV.

† Dunér, the above mentioned memoir, p. 12.

‡ Spoerer, Publ. d. Astroph. Obs. z. Potod. Bd. IV, St. 4; 1886.

obtain the following picture of a spot: In the condensed vapors of the photosphere is a cavity or depression, upon the floor of which lies a layer of cooled vapor. How is it then, in general, explainable that a cavity of this sort is formed of several hundred miles extent in this condensed mass of vapor, and can besides continue for months, and further that such a difference in temperature between this cooled layer of vapor and the photosphere can be sustained so long? Such a cavity is only conceivable when gases or vapors of higher temperature exist in it which hinder a condensation of the photospheric vapors. In a spot, then, there must be an extreme reversal of temperature; this is confirmed by the frequent diminution of the lines, which appear in the higher regions of the chromosphere, and their frequent reversal; it is confirmed by the recent observations of Frost, that spots may occasionally be warmer than the surrounding photosphere.* Above the layer of cooled vapor there prevails a heat which is abnormal considering its height above the surface of the Sun; this may be explained readily and only by an atmospheric current flowing down from the chromosphere upon the photosphere. The action of such a current may be completely explained by recent meteorology; especially the fundamental researches of Hann† on this subject which I shall follow thought by thought. From these we have the following results with reference to an ascending current of air:

The mean temperature of the column of air in which the upward motion takes place is far above the usual average; the air within is of extraordinary clearness and dryness. At a certain distance from the Earth's surface the ascending motion must naturally cease, and be transformed into a correspondingly slow horizontal motion; in this part of its path the air is cooled by radiation of heat, which is unusually favored by the clearness and dryness of the upper strata of the air. It is in consequence of this great fall in temperature that those dense clouds are formed, which under such circumstances occupy the lower strata. In the descending column of air the atmospheric pressure is abnormally high.

Have we not in the case of the Sun a nearly complete analogue of the above explanations? The clearness of the photosphere, the quiet of the deeper strata, and their greatly lowered temperature. Since it has also been satisfactorily proved by observa-

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* Frost, A. N., Bd. 130, No. 3105-06, p. 143; 1892.

† Hann, Zeitschr. f. Meteorol., Bd. X, p. 210, 1875; Bd. XI, pp. 129-135, 1876; Denkschr. d. W. Ak. d. Wiss. Bd. LVII, 1890.

tion, that a motion directed toward the spot takes place from above,—Spoerer himself has in fact, observed numerous instances in which such currents have been drawn directly toward the spot*—we seem to be limited to some such explanation of the spots, especially when, in addition, we consider that on the Sun these energies must be of much greater intensity than on our Earth. The greater portion of the radiation from the photosphere is absorbed by the gases and vapors lying over it, above all the deeper lying metallic vapors with their numerous lines taking the principal part in this; the upper strata of the chromosphere consists of gases and vapors of relatively little power of absorption; among these are helium, hydrogen, sodium, and calcium. A current which consists principally of these latter substances, and carries with it vapors at a very high temperature only, *e. g.* iron vapors, I will call dry, in contradistinction from such currents as are saturated with vapors, and which I shall call saturated currents. If, now, a saturated current thus flows upward from the photosphere into the chromosphere, and naturally sinks down again somewhere as a dry current, it will have a much higher temperature than it had when it left the photosphere; this results because in its ascent which is naturally accompanied by cooling it must continually condense vapors, which thereby transfer to it their condensation-heat and thus greatly check its cooling.† Descending currents are, therefore, always associated with great heat and dryness, since the vapors which they may happen to contain, being at a high temperature only, exert no influence worth mentioning. When, therefore, such a current strikes the photosphere and remains there, it will, in consequence of its much higher temperature, free the vapors which are there condensed, and by its continual inflow produce great dryness along its path; the consequence of which will be to cause a clearing of the photosphere in this place, which must resemble a funnel shaped cavity; finally the vertical current will branch into horizontal currents, and beneath these places of branching, where the gases must stagnate, we have now conditions suited to a powerful radiation; at this point a considerable fall in the temperature ensues, which is proved by the layer of gas or vapor forming a nuclear spot. The sides of the funnel also naturally radiate heat, although to a much less extent, since they are inclined to the surface of the Sun, and form the penumbra of the spot. I

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* Spoerer, Publ. d. Astroph., Obs. z. Potsd., Bd I. St. 1, No. 1, p. 79: 1878.

† A saturated moist ascending atmosphere undergoes a diminution of temperature of 0°.54 for every 100 m at 10°; a dry atmosphere one of nearly 1°, thus nearly double that of a moist one.

will not here further consider how observations made directly and with the spectroscope agree with these ideas; this will be done in another place.

We have really completed the solution of the problem given, to explain the origin of the spots; I may however be further permitted to point out how this theory of the Sun spots fulfils every demand made upon it: it explains, in fact, the rotation and heliocentric distribution of the spots. If we assume the Suu spots as the domain of the descending currents, which naturally must ascend somewhere else, and further consider that they arrange themselves in zones, this suggests a common origin, which may be supposed to be at the equator, but in reality is not to be sought there but in the polar regions, since a zone of spots in lower latitudes may reach clear to the equator, while in the the higher latitudes—and this is always the case near the time of minimum—a new vigorous succession of spots is already begun. Thus ascending currents similar to those at the equator in our atmosphere, prevail at the polar regions of the Sun and flow at a certain elevation in long extended spirals toward the lower latitudes where they appear as east winds, and when they descend, as spots. Until a branch current from the pole reaches the lower latitudes, months, perhaps years, elapse; this depends on the velocity of the upward flow. If we suppose the upward flow at the poles alternately increasing and decreasing in intensity, we have, as may easily be seen, the following as the origin of the heliographic distribution of the spots: If, at the time of minimum, the intensity is increasing, the spots will at this time sink in higher latitudes; with the constantly increasing intensity the lower latitudes become scattered over with spots; the spot maximum intervenes, and the current may be almost destroyed, while the east winds still circling about the Sun will sink finally as minimum spots in the neighborhood of the equator; meanwhile the series of phenomena has already begun anew. This upward flow thus explains the heliographic distribution in an extremely simple manner, and at the same time explains the individual rotations of the different latitudes on the Sun. The currents flowing from the poles are accompanied by small velocities, and consequently small angles of rotation, since according to Zoeppritz* and Wilsing† friction in the lower strata has very little influence, and they also, on this account, continue for a long time; if however they have revolved about the Sun several times, an influence will be exerted,

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* Zoeppritz, Wied. Ann. N. F. Bd. III, p. 582, 1878.

† Wilsing, A. N., Bd. 127, No. 3039, p. 233, 1891.

such as to cause the east winds of the lower latitudes to show a greater daily angle of rotation than those arising in higher latitudes, which were much less displaced by friction.[*] The appearances on the Sun's surface also suggest with great probability the upward flow existing at the poles. The polar regions are the calms of the Sun; the often gigantic dimensions of the cloud protuberances, principally in the neighborhood of the poles, continue during a whole revolution, and appear to favor this theory. Especially may this be said of cloud protuberances lying in a horizontal direction, the average height of which exceeds that of all the others which float freely above the photosphere and without visible connection are renewed from beneath, though here and there united by little columns. If the higher temperature of the poles is not the origin of this polar current the latter must at any rate increase the polar temperature. The poles at certain times thus become warmer than the equatorial regions; this, if it can in general be demonstrated, will be most pronounced at the time of minimum, when the succession of spots begins in higher latitudes. This statement is supported by the otherwise wholly enigmatic behavior of the chromosphere, which at the time shows "accumulations" at both poles, while the year before the minimum it shows a uniformity in height extending over all latitudes. By this theory of Sun-spots the problem of the rotation of the Sun, that of the number of the spots, and also that of their heliographic distribution, seem to be reduced to a single problem, namely, that of a periodic upward current in the polar regions. The many further evidences of the ideas here merely suggested, and the further results to which the theory has led me with reference to the constitution and temperature of the Sun, and the nature and constitution of the different protuberances, I propose to present in a work soon to be completed.

DISTRIBUTION IN LATITUDE OF SOLAR PHENOMENA OBSERVED DURING THE FOURTH QUARTER OF 1892.[*]

P. TACCHINI.

The following are the results on the distribution in latitude of solar phenomena observed during the months of October, November, and December, 1892:

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[*] This is the same idea as that which forms the basis for Zöllner's rotation theory.

[†] Communicated by the author.

Latitude.	Prominences.		Faculæ.		Spots.	
90 + 80	0.000	0.399				
80 + 70	0.015					
70 + 60	0.105					
60 + 50	0.049					
50 + 40	0.016		0.004	0.431		
40 + 30	0.051		0.026		0.010	0.442
30 + 20	0.078		0.086		0.019	
20 + 10	0.040		0.177		0.250	
10 + 0	0.045		0.138		0.163	
0 − 10	0.044	0.601	0.056	0.569	0.106	0.558
10 − 20	0.082		0.203		0.202	
20 − 30	0.100		0.211		0.221	
30 − 40	0.138		0.086		0.029	
40 − 50	0.074		0.013			
50 − 60	0.125					
60 − 70	0.036					
70 − 80	0.002					
80 − 90	0.000					

The prominences, faculæ and spots have thus been more frequent in the southern hemisphere; metallic eruptions have been wholly absent, at least according to our observations. This is certainly a peculiar condition, for it is rare that spots and faculæ are so numerous without accompanying eruptions. The spot groups have had their maximum of frequency in the zones (+ 10° + 20°) and (— 10° — 30°), exactly as in the preceding quarter, and in accord with the faculæ. The prominences, on the contrary, present their maximum of frequency in zones more distant from the equator, where we have observed neither faculæ nor spots.

R. OSSERVATORIO DEL COLLEGIO ROMANO,
Rome, March 9, 1893.

ON THE DISPERSION OF AIR.*

C. RUNGE.

The wave-lengths of light are generally given for air of a certain temperature and a certain pressure. Rowland's standard wave-lengths, for instance, are given for air of 20° Celsius and a pressure of 760 mm. of mercury, and all wave-lengths that are deduced from these by interpolation or by the method of coincidences also refer to the same temperature and pressure. With the change of the density of the air the wave-lengths change inversely proportional to the index of refraction for each particular color.

Now it is necessary for some purposes to take this change into

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* Communicated by the author.

account and to reduce the wave-lengths to vacuo by multiplying them by the index of refraction that corresponds to them. The laws, for instance, that govern the distribution of lines in the spectrum of an element must be independent of the alterations, which the wave-lengths undergo on account of the particular temperature and pressure of the air in which they are observed. Thus in many spectra there have been observed a number of pairs of lines, whose wave-lengths λ_1, λ_2 give the same value of $\frac{1}{\lambda_1} - \frac{1}{\lambda_2}$. This law can be true only approximately unless the wave-lengths are reduced; for it cannot depend on the temperature and pressure of the air. Although the approximation is great on account of the index of refraction having nearly the same value for all wave-lengths considered, there are cases where the difference is appreciable, as for the widely separated pairs of lines in the spectrum of Thallium.

As a further instance of the necessity of reducing wave-lengths to vacuo one may mention, that if the accuracy in the determination of wave-lengths were extended to less than one-hundredth of an Angström unit one would have to take account of the dispersion of air even in the method of coincidences. For a change of say four per cent in the density of the air might separate perceptibly two wave-lengths in the spectra of the first and third order that coincided before.

The dispersion of air has been measured by Ketteler, by Mascart and by Lorentz. Ketteler has determined the indices of refraction for three colours: Lithium 6708, Sodium 5893, and Thallium 5351, and Lorentz has repeated his measurements for the first two colors. Mascart has chosen four rays of Cadmium 6439, 5379, 5086, 4800 besides Sodium 5893. These are, as far as I know, the only determinations of dispersion. There exist besides a number of determinations for white light and several for Sodium light. But for wave-lengths shorter than 4800 no measurements of the index of refraction seem to have been made.

Professor Kayser and I have thought it necessary to measure the dispersion as far as we could photograph the wave-lengths. We have recently completed this work, and the full description of our method and observations is shortly to be published by the Berlin Academy of Science. The results may interest the readers of ASTRONOMY AND ASTRO-PHYSICS.

The dispersion was measured by letting the rays reflected from a large concave grating of Rowland pass through a prism of compressed air and measuring the deviation. Thus we found for dry air:

Wave-length.	Index of refraction for 0° and 760mm.	Weight.	Wave-length.	Index of refraction for 0° and 760mm.	Weight
5630	1.0002927	2	2860	1.0003088	1
4430	1.0002955	3	2850	1.0003094	2
4200	1.0002967	3	2550	1.0003158	2
3250	1.0003035	3	2360	1.0003219	1

These values agree very well with Cauchy's formula,

$$n = a + b\lambda^{-2} + c\lambda^{-4},$$

where n is the index of refraction, λ the wave-length and a, b, c positive constants. By the method of least squares we have calculated the formula $n = 1.00028817 + 1.316\ \lambda^{-2} + 31600\ \lambda^{-4}$ where λ is expressed in millionths of a millimetre. The greatest difference between the observed and calculated values amounts to 2 units of the last decimal. This formula allows to find the indices of refraction for other wave-lengths besides those of the observations. All measurements of the refraction of air for Sodium light, that have come to our knowledge are arranged chronologically in the following table:

Ketteler	1.0002947 in 1865
Mascart	1.0002927 in 1877
Lorentz	1.0002911 in 1880
Benoît	1.0002923 in 1888
Chappuis and Rivière	1.0002919 in 1888
Kayser and Runge	1.0002922 in 1893

As to the differences of indices for different colors our observations agree perfectly well with Ketteler's and Lorentz' observations and fairly well with those of Mascart. But the part of the spectrum that the measurements of these physicists comprise is far too small to allow an extrapolation for the whole. This is most evident, if a curve is platted whose ordinates are proportional to n and whose abscissæ are proportional to λ^{-2}. The curve will be nearly a straight line only slightly curved to a parabola. Now the former observers have measured this curve between $10^8\ \lambda^{-2} = 222$ and $10^8\ \lambda^{-2} = 434$, while our determinations allow to follow it to $10^8\ \lambda^{-2} = 1796$, that is, more than seven times as far. From our results the following table of corrections is calculated for reducing to vacuo Rowland's standard wave-lengths and all wave-lengths that are determined from them by interpolation.

Wave-lengths.	For reduction to vacuo add:	Wave-lengths.	For reduction to vacuo add:
8000	2.164 Ångström	4000	1.109 Ångström
7000	1.898 "	3000	0.857 "
6000	1.633 "	2500	0.739 "
5000	1.369 "	2000	0.635 "

For intermediate values of λ a linear interpolation gives the values exact within 0.002. These numbers we believe to be correct almost to unity of the last decimal.

There is a similar table of corrections given in the introduction to Watts' Index of Spectra, which is calculated from Ketteler's determinations of the refraction of air. The discrepancy between that table and ours is considerable, which is in a small degree duc to the difference between Ketteler's and our observations and the wider range of the latter, but principally to the circumstance that Watts has not taken account of the temperature. He applies Ketteler's indices of refraction, which correspond to 0° Celsius to reduce wave-lengths that are measured at 16° Celsius. He ought, as we have done, to have computed the indices of refraction that refer to the same temperature to which the wave-lengths correspond and from them to have deduced the corrections.

The fact mentioned above, that one might have to take account of the dispersion of air in determining wave-lengths by the method of coincidences is clearly seen from the table of corrections. Suppose at a temperature of 20° Celsius and a pressure of 760 mm. two rays have the wave-lengths 6000 and 2000. They would then exactly coincide, if one was observed in the first the other in the third order. Now reduce both rays to vacuo. They would no longer coincide, the ray in the third order lying to the less refrangible side by $0.635 \times 3 - 1.633 = 0.272$. Since the corrections are proportional to the density of the air a barometric pressure of say 770 mm. and a temperature of 12° Celsius would make the distance between the two lines 0.011, an amount which is larger than the probable error that may be reached with well defined lines.

HANOVER, Germany, March 27, 1893.

ON THE VARIABLE STAR ALGOL.

BY THE LATE PROFESSOR WILLIAM FERREL.*

It has long been observed that many of the fixed stars vary in brightness, their maxima and minima recurring at regular periods, which vary in different stars from a few days to many years, and the variation of their brightness amounting, in some

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* From "The Nashville Journal of Medicine and Surgery," April 1855, vol. VIII, pp. 277-282. Professor Cleveland Abbe has been kind enough to furnish a MS copy of this paper, which we reprint for its historical interest in connection with the recent investigations of Vogel and Chandler.

cases, to a total extinction of their light. The most remarkable and interesting of these is the star Algol, in the constellation of Perseus, both on account of the shortness of its period and the rapidity with which it changes from its ordinary brightness to its minimum, and back again. It was first discovered to be a variable star by Goodricke, in the year 1782, and it was observed that it remained at its ordinary brightness of a star of the second magnitude for about two days and 14 hours, when it rapidly changed in about 3½ hours to a star of the fourth magnitude, and then back again in about the same time to its ordinary brightness, completing a period in 2 days, 20 hours, 48m., 59s. So great was the regularity of its period at first, that 36 years after Goodricke discovered it to be a variable star, all the observations could be represented by a uniform period; but it has been shown by modern observations that its period is diminishing. Professor Argelander of Bonn, has been interested in this subject for several years, and although the number of observations of minima, especially in the first part of the present century, has been very few, so much so that for the first 40 years of the present century he only knew of 19 observed minima, yet from a discussion of all the observations made by himself and others, he has shown very conclusively, first that the period is diminishing, and secondly, that the diminution is not in proportion to the time. By treating the observations by the method of the least squares, he has arrived at the results given in the following table:

Periods of Algol.

Date	Length of Period.				
	d	h	m	s	s
1784, May 27	2	20	48	59.42	± 0.32
1788, Dec. 21				58.74	± 0.09
1793, July 11				58.39	± 0.18
1805, Nov. 25				58.45	± 0.04
1818, April 13				58.19	± 0.10
1830, July 3				57.97	± 0.05
1842, Sept. 20				55.18	± 0.35
1848, July 18				53.37	± 0.98

It is evident from the nature of the observations that no one observation can give anything like a reliable result. In order, therefore, to arrive at a knowledge of the law by which the period varies it will be necessary to have a great many observations, taken by different observers, at different times and places, so that the mean of all may be taken, and so that by discussing different sets of observations we may know what reliance may be placed on the accuracy of the results. Professor Argelander is therefore desirous that the number of observers should be greatly increased, and he has, accordingly, published an article in the *Astronomical Journal*, Cambridge, Mass., in which he earnestly entreats American astronomers to give their attention to the subject. In order to facilitate the observations, he has computed the approximate times of all the minima visible in America during the present year. Those belonging to the remaining part of the year (1855) are given in the following table:

Minima of Algol, Visible in America, Washington Mean Time.

		h	m			h	m			h	m
April	12	9	16	Sept.	2	17	49	Nov.	10	13	18
May	19	15	52		5	14	38		13	10	7
June	11	14	22		8	11	27		16	6	56
July	1	16	3		11	8	16		27	18	11
“	4	12	52		25	16	19		30	15	0
“	7	9	41		28	13	7	Dec.	3	11	49
“	24	14	31	Oct.	1	9	56		6	8	38
“	27	11	20		4	6	45		9	5	27
“	30	8	9		15	17	59		20	16	43
Aug.	13	16	11		18	14	48		23	13	32
“	16	12	59		21	11	36		26	10	21
“	19	9	48		24	8	25		29	7	10
“	22	6	37	Nov.	7	16	29				

I have noticed this subject in a Southern journal, at the suggestion of Dr. B. A. Gould, Jr., of the *Astronomical Journal*, in a private letter which I have had the honor to receive, in the hope that there may be some amateurs of the science in the South who will be willing to respond to the call of Professor Argelander, and give their attention to this interesting subject. Any one can make the observations, as no instruments are required, and it is not necessary to secure the time with a very great degree of accuracy. Dr. Gould very kindly offers to furnish any one who may be disposed to make the observations, with a copy of the number of the *Astronomical Journal* containing Professor Argelander's article, in which directions are given for making the observations.

I would here suggest that the diminution of the length of the periods may be owing to a variable diminution of the distance between us and Algol, just as the periods of the satellites of any of the planets would appear to vary annually if no allowance were made for the equation of light. But it is evident that the diminution of the distance would only produce a change in the length of the period without affecting its uniformity. It is also evident that the variation of distance which would account, upon our hypothesis, for the diminution of the period, cannot result from a change of distance on account of the proper motions of the Sun and of Algol around some great central Sun of the universe, as Mædler's; for such motions, being connected with great revolutions and immense periods of time, would produce an apparent diminution in the period, which would not differ sensibly, in a few centuries, from a uniform diminution, which is entirely at variance with the observations which have been made. A variable diminution of the distance, then, between the solar system and Algol, such as would account, upon our hypothesis, for the phenomenon in question, can only arise from some revolution of the Sun or of Algol, connected with a comparatively short period of time, as a few centuries. But we know that the Sun has no such motion, and therefore, if there is any such motion it must be connected with Algol. But here the question naturally arises, where is the centre of attraction around which Algol revolves? I answer some large opaque body in its vicinity. Now, this may seem like very unphilosophically inventing a very improbable hypothesis in order to account for a particular phenomenon; but it is precisely the conclusion to which Bessel came from other considerations, with regard to Sirius and Procyon. From a discussion of the most accurate observations which have been made upon these stars, he ascertained that their motions deviate sensibly from uniformity, and hence he inferred that they must each revolve around some non-luminous body in their vicinity, and consequently that they are double stars, one of the members of which is non-luminous. That Algol may be a star of this kind, and that there are many opaque bodies in space of the size of our Sun, as Bessel supposed, I do not consider very improbable, since it is well known that, even within the last century, many stars have disappeared from the heavens and consequently, unless they have been annihilated, which is improbable, they must now exist as opaque and invisible bodies in space. And if we suppose the same thing to have happened for innumerable ages before, there must now be very many such bodies in space, and hence there may be many such double stars as Bessel supposed Sirius and Procyon to be. In fact, suns or stars, like almost everything else, seem subject to mutations, and after going through a series of physical changes, or perhaps cooling down to a certain temperature by the radiation of heat, seem suddenly to cease to shine; and our own Sun, which has been known to have dark spots on its surface 50,000 miles in diameter, may now be in the last stages of incandescence, and ere long cease to shine, and be as a missing star in the firmament of other systems of worlds. But it matters not, so far as our first hypothesis is concerned, whether there are opaque bodies in space or not, to produce a variable

in the stars, provided it is an established fact, that they
this kind of motion, and that this motion in Algol is ade-
) account, upon our hypothesis, for the observed diminu-
the period.

s now endeavor to determine whether the hypothesis of
motion in Algol is consistent with what we know of
ion, or of the motions of stars in general, based
servations of their proper motions, and calculations
distance. Without going into an accurate investiga-
the subject, by means of mathematical formulæ, it may
determined approximately, from the table of diminish-
ods which has been given, that the minima of 1848 oc-
bout 16000 seconds earlier than they would have done
length of the periods not been diminished any since the
'84. This number multiplied by 190,000 miles, the dis-
rough which light passes in a second, gives in round num-
out 3,000 millions of miles for the space through which
t would pass in that time. Hence, in order to account for
ima's occurring 16000 seconds earlier and for the conse-
radual diminution of the periods, it is only necessary to
that Algol, in 1848, was 3000 millions of miles nearer
r system than it would have been had it moved on with
e uniform velocity which it had in 1784. Great as this
is, at the distance of Algol it could only be detected by
st accurate observations. For according to Struve, the
parallax of stars of the second magnitude is a little over
econd, a motion of 3000 millions of miles in an arc at Al-
ld only subtend an angle of about 3 seconds. If we sup-
variation of distance to be produced by the motion of
an orbit, it is evident, that about the year 1784, and
s motion must have been for the most part in a direction
e solar system, and consequently it would not have af-
ts apparent proper motion to the amount of 3 seconds.
ariation of 3 seconds from uniformity in the proper mo-
f the stars since the year 1784, could not have been de-
nless by the most accurate observations. Hence, if even
ble motion in any of the stars had never been detected, our
esis is not at variance with anything we know about the
of the stars, and is in some measure confirmed by the
ry of Bessel. An orbit with a period of several centuries
e assigned to Algol, upon our hypothesis, with such eccen-
nd position, that the equation of light, applied to the ob-
ons which have been made, would render the periods very

nearly equal, and in the course of time, the orbit might be pretty accurately determined from the observations of the minima; and then this, together with the observations upon the variable proper motion of Algol, if such motion should ever be detected, might furnish much more reliable data by which to calculate the *distance* of Algol, than any which we now have. It is considerations of this kind which invest this subject with a very high degree of interest.

NOTE ON THE SPECTRA OF THE FLAMES OF SOME METALLIC COMPOUNDS.*

G. D. LIVEING AND J. DEWAR.

A study of the spectra of flames offers many points of interest. It is long since A. Mitscherlich (*Poggendorff's Annalen*, vol. 116, p. 499; vol. 121, p. 459) showed that the spectra of flames are, for the most part, those of compounds of the elements present, and contain comparatively few rays proceeding directly from the elements themselves. But there are many questions still undecided. For example, it is not known whether the vibrations which give the spectra of compounds in flames are those which the molecules of the compounds in question would assume under the action of a high temperature alone, or whether they are not vibrations of a different order, arising during chemical changes, and deriving their energy directly from the chemical energy of the interacting substances. When the absorption spectrum of a compound is observed to correspond with its emission spectrum in a flame, we may infer that the vibrations are those which the compound molecule assumes when sufficiently heated. But there are not many cases in which this has been observed. We have observed it in the case of cyanogen (*Roy. Soc. Proc.*, vol. 44, p. 247, note), but we are not certain of any other case. The difference between the spectrum of the base of a flame and that of the upper part, observed in many flames, lends support to the supposition that there are rays which originate in the chemical change, perhaps occurring in the molecules which are in intermediate stages of the change, and not assumed by the molecules which are the final product, even when intensely heated in the upper part of the flame. The fact that the same rays which are seen in the base of a flame may be sometimes generated by electric discharges in the gases

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* *Proc. Roy. Soc.*, Vol. LII. pp. 117–123.

ch are burnt in the flame, or in their products of combustion, iot at all inconsistent with this supposition, for such disrges certainly have electrolytic effects, and may very well give to molecules in the intermediate stages between one state of nical combination and another.

is sometimes assumed in books on chemistry that the atoms ch form a chemical compound can never be in an intermediate te between complete separation and complete combination. inconceivable an assumption would hardly have been made ept to support a theory, but it has nevertheless obtained a ain currency. It is supported by no fact and no analogy. o atoms which are within the spheres of each other's influ, but have not yet reached the state of relative tranquility ch we recognize as chemical combination, may very conceiv be the seat of very violent agitation and vibratory motions, ch cease when they are actually combined. The flames of subices, such as the organo-metallic compounds, into which als enter as chemical ingredients, have not hitherto, so far as know, been observed, and it is to two such flames that these es refer.

SPECTRUM OF THE FLAME OF NICKEL-CARBONYL.

he remarkable compound of nickel and carbonic oxide, $Ni(CO)_4$, overed by Mr. Mond, burns in air with a luminous, smoky ne, and the spectrum it emits appears to be a continuous one. en the vapor is burnt in oxygen instead of in atmospheric air, spectrum still appears to be quite continuous; in fact, such a ctrum as carbonic oxide, without any nickel, gives under simicircumstances. This, however, is only in appearance, because brightness of the continuous spectrum overpowers the ler bands and lines which belong to the flame of the el compound. These bands and lines come out when the or of the nickel compound is diluted with a good deal of lrogen. We have employed two methods of making such a ture. The first was by passing a stream of dry hydrogen, ed with carbonic oxide, over reduced nickel in a glass tube, burning the issuing gas in a double jet with oxygen either side or inside the burning gas. The nickel was freshly reduced gentle heat with hydrogen, and allowed to cool in carbonic de. When quite cold the stream of mixed hydrogen and carlic oxide was found to take up quite enough nickel at the temature of the room, and would continue to do so for some irs. After a time, however, the nickel required to be again

warmed in a current of hydrogen, when some water was give
off, and the metal recovered its sensitiveness. Another plan wa
to pass a stream of hydrogen through a U-shaped tube co
taining a little of the liquid nickel compound in the bend. Th
result was the same in each case, but the proportion of vapor o
the compound was more easily varied (by simply varying the pro
portion of carbonic oxide in the stream of gas) in the forme
method. The mixed gas and vapor burnt in air with a smok
flame, but in a full supply of oxygen with a bright yellowish
green flame without visible smoke. The first jet we used was o
platinum, but nickel-carbonyl deposits nickel at a red heat, s
that the platinum soon became coated with a thick deposit o
nickel, which choked the orifices. This nickel adhered so closel
to the platinum that it could not well be removed mechanically
and had to be dissolved off. We found it therefore more conven
ient to use a jet made of a piece of porcelain tube, about 1 cm. i
diameter, with a narrow porcelain tube, fitted by means of
cork, in the axis of the wider tube. The mixed gas and vapo
were passed either through the inner or through the outer tub
and oxygen through the other. The porcelain being a bad con
ductor, no nickel was deposited on it, except close to the orific
whence it could be easily removed mechanically without dis
turbing the apparatus. The porcelain, of course, added som
lines to the spectrum, but these were easily detected. In fact, w
noticed only the lines of sodium, calcium and lithium.

The spectrum of the flame of the nickel-carbonyl thus dilute
consists of two parts: (1) the spectrum of the main body of th
green flame; (2) that of the base of the flame when the oxygen i
outside, and of the surface of the small inner cone when the oxy
gen is inside, the flame.

The spectrum of the main body of the flame consists of a serie
of shaded bands, brightest in the green, but extending on the re
side beyond the red line of lithium, and on the violet side well int
the blue, though with rapidly diminishing distinctness. Thes
bands have their sharp bright edges on the more refrangible side
that is, they are turned in the opposite direction to the band
produced by electric discharges in carbonic oxide at low pressure
The positions of the bright edges of the bands in the flame of th
nickel-carbonyl have some correspondence with those of the band
produced by electric discharges in carbonic oxide, but it is not
very close one, and may be only accidental. With the dispersion
employed, which gives a difference of deviation of 2° 52′ between
D and F, there was no sign of a resolution of these bands int

s. The brightest bands had, however, their more refrangible
es pretty sharply defined, while the less bright bands, especi-
· those in the blue, were very hazy. A certain amount of con-
ıous spectrum, of course, overlay the bands, and made them
ıewhat less distinct. Photographs show that this continuous
ctrum continues as far as λ 3500, but fading sensibly from λ
0 onwards. The photographs do not show any extension of
bands beyond the blue.

esides the bands a few lines, but only a few, in the visible part
he spectrum, extend into the upper part of the flame. Of these
only one is a known line of nickel; it is the green line λ 5476.
s was also the only line of nickel which we observed in the vis-
part of the spectrum in explosions of hydrogen and oxygen
nickel-lined tube (*Roy. Soc. Proc.*, vol. 36, p. 475).

ı the ultra-violet part of the spectrum of the flame a great
ıber of nickel lines were photographed; indeed, by far the
ater part of the lines of nickel found by us in the arc (*Phil.*
ns., vol. 179 (1888) A, p. 247), are between λ 3972 and
943.5. In this case also there is a close correspondence be-
en the spectra of the flame and of the explosions, except that
lines of the flame are much more numerous than those re-
ded of the explosions. This difference, however, is probably
to the much shorter exposure of the photographs of explo-
ıs. Although the photographs show lines as high as λ 2943,
lines in this region are very faint, and gradually die out in
ceeding from the less to the more refrangible side of the spec-
n. In the region about L, M and N the lines are very strong,
that it is for rays of those rates of vibration that nickel is
t sensitive at the temperature of the flame.

ırning now to the base of the flame, we find a great number
ines, of which most extend but a short distance from the bot-
ı of the flame. They form two principal groups, one in the
nge and red, and the other in the citron and yellow. These
s are for the most part sharply defined, and in the more
angible parts of each group very fine and closely set. They
probably channellings following Rydberg's law, and some-
ıt confused by overlapping.

one of these lines appear to be nickel lines, and, as they are
ted to the base of the flame, they cannot be ascribed to any of
final products of the combustion, such as nickel oxide, but
st be due either to the as yet unaltered molecules of nickel car-
yl, or to some molecules intermediate between that compound
the products of combustion which have only a transitory ex-

istence, and may, perhaps, have a transitory agitation of a pa ticular kind imparted to them by the chemical energy whic changes its form in the combustion.

The following table gives the approximate oscillation freque cies of the edges of the principal shaded bands, and of the lin seen at the base of the flame, but the numbers are only appro mate:

OSCILLATION FREQUENCIES OF EDGES OF SHADED BANDS.

1496	1692	1933	2146
1521	1752	1960	2172
1577	1808	2052	2199
1594	1849	2107	2226
1635			

OSCILLATION FREQUENCIES OF LINES IN THE BASE OF THE FLAM

1497	1582	1622	1721
1506	group of very	1627*l*	1727*l*
1509	closely set lines	1631*l*	1732*l*
1514	1586	1651	1735
1518	1593	1656	1738
1521	1595	1663	1741*l*
1526	1596	1667	1742
1543	1598	1671	1745
1547	1599	1673	1746
1549	1600	1682	1747
1555	1602	1686	1753
1560	1604	1690*l*	1806
1563	1607	1706	1809
1572	1612	1712	1827
1575	1615	1714	1833
1578	1616	1716	1879
1580	1618		

The six numbers in the above table to which an *l* is added corr spond to lines which extend into the upper part of the flame.

TABLE OF WAVE-LENGTHS OF NICKEL LINES PHOTOGRAPHI FROM THE FLAME.

2943.5	3053.9	3194.9	3285.0	3409.0	3483.1	3587.2	3737.0
2981.2	3057.2	3196.6	3315.1	3413.4	3485.2	3601.4	3745.0
2983.6	3064.2	3201.5	3319.7	3413.8	3492.3	3609.8	3775.0
2992.2	3080.3?*	3221.1	3321.6	3423.1	3500.0	3612.1	3783.0
2994.1	3096.6	3224.6	3361.0	3433.0	3509.7	3618.8	3791.0
3002.1	3098.6	3226.3	3365.5	3436.7	3514.4	3624.1	3806.6
3003.2	3101.1 ⎫	3232.6	3367.2	3445.7	3519.1	3663.4	3831.7
3011.5	3101.4 ⎭	3234.2	3368.9	3452.3	3523.9	3669.7	3857.8
3018.8	3105.0	3242.6	3371.3	3457.8	3527.1	3673.4	3972.0
3031.4	3113.7	3247.8	3373.6	3461.1	3547.5	3687.6	
3037.5	3133.6	3250.1	3380.0	3466.8	3561.1	3694.6	
3044.5	3145.5	3270.6	3390.4	3468.9	3565.7	3721.6	
3050.4	3183.8	3282.2	3392.4	3470.8	3571.2	3736.1	

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* A query is placed against this number because the water spectrum is strong at this point that we cannot certainly distinguish the nickel line. There no other reason for doubting its presence.

ie more refrangible lines in the foregoing table were very
tly depicted on the photographic plate, and it is possible that
ore lengthened exposure than the fifteen minutes, which we
loyed in the region where the lines were faint, would have
ight out more lines. The continuous spectrum of the lime-
t extends some distance further than the most refrangible of
e nickel lines.

FLAME OF ZINC ETHIDE.

ic ethide burning undiluted produces so much continuous
trum as to overpower any special rays. But by passing a
am of hydrogen through a bent tube containing zinc ethide,
burning the mixed gas and vapor in oxygen, as we did the
el-carbonyl, we reduced the continuous spectrum sufficiently
iable us to observe any fairly strong rays which might be pe-
ir to the flame. In the visible part of the spectrum the three
-known rays of zinc in the blue λ 4812, 4721, and 4681 were
y seen. Photographs of the more refrangible part of the
trum showed no trace of the ultra-violet lines of zinc; no
e, in fact, than the flames of hydro-carbons usually show.
did there appear to be any rays from the base of the flame
r than those seen in hydrocarbon flames in general. In our
rvations on explosions (*loc. cit.*) we did not find that a zinc
g to the tube in which the oxyhydrogen gas was exploded
ght out any zinc lines, either in the visible or the ultra-violet
of the spectrum. The flame of the compound containing
chemically combined may be supposed to give the rays of
more readily than the exploding gases, which merely take up
netal mechanically. But the flame does not, in either case,
hot enough to develop the ultra-violet rays, though these
very strongly developed in the arc.

A CERTAIN ASYMMETRY IN PROFESSOR ROWLAND'S CONCAVE GRATINGS.*

J. R. RYDBERG.

In order more especially to obtain a series of observations
d for a continuation of the studies on the spectra of the élé-
ts of which the commencement has been published in my
cherches sur la constitution des spectres linéaires des élè-

Philosophical Magazine No. 214.

ments, chimiques" (*K. Svenska Vetensk. Akad. Handl.* B XXIII, No. 11), a spectroscope with one of Professor Rowland concave gratings (10,000 lines to the inch) was procured for th Physical Institution of the University of Lund. It was mounte in a most excellent manner by the Mechanician of the Physiolog cal Institution, Hilding Sandström, according to the instructio of Professor Rowland (*see* Ames, Johns Hopkins Universit Circulars VIII, No. 73, May 1889; ASTRONOMY AND ASTR PHYSICS, January 1892 but with full freedom in the details of co struction. The adjustments also were executed according t the same instructions, but with greater precision in the speci determinations with the intention to obtain by the exactness the adjustment the same scale through the whole spectrum.

However, when all adjustments were completed, no distinct in age could be obtained in any part of the spectrum. In the visib spectrum of the first order the image was not very much out focus, but the deviation increased gradually, so that it becam necessary to displace the eyepiece several centimeters to obtai well-defined images of the spectra of higher orders. All detai being executed with the same accuracy, there was nothing th could indicate the cause of the discrepancy, so that nothing r mained but to make all the adjustments over again, determinin at the same time the extreme limits of the errors. For this pu pose I have made use of new methods of adjustment, and I hav ascertained by these researches:

1. That the courses which the apex of the grating and th cross hairs of the eyepiece follow in their movement on the rai do not deviate in any point from straight lines by more than 0. millim.

2. That the angle formed by the average directions of the rai did not differ from a right angle by more than 15″ (correspon ing to an arc of 0.5 millim. at one of the ends of one of the rails the difference probably not amounting to more than a third this value.

3. That the middle of the slit could not be more than 0.2 millin from the crossing-point of the lines that are described by th apex of the grating and the cross hairs of the eyepiece.

4. That the apex of the grating and the cross hairs of the ey piece were not more than 0.1 millim. distant from the axes of th carriages.

5. That the distance between the centre of curvature of th grating and the axis of the carriage on which the eyepiece wa placed, did not amount to 0.5 millim. during the whole mov ment.

hat the lines of the grating and the direction of the slit
arallel and at right angles with the plane of the rails.
'hat the grating was entirely free from all constraint and
erical form, the images in the centre of curvature being of
nt definition.
'hat the optical state of the slit was perfectly normal.
these results it was only in the grating itself that the
of the displacement of the spectra could be looked for,
in some imperfection of the theory or in some fault in the
ion of the work, at least with regard to the special grating
tion. Hitherto, I had not deemed it possible to make any
e assumptions, as it seemed that Professor Rowland him-
d other spectroscopists who have used the concave grat-
ight to have recognized such an anomaly, if it existed.
ng all the adjustments the grating was left in the same po-
n its holder, so that I had made use only of the spectra on
le of the grating. Now it was removed from its holder
fter being reversed, it was adjusted in the same manner as
with the intention of learning whether the focal curve
asses through the centre of curvature is symmetrical with
to the principal axis of the concave mirror. Then it was
that the distance between the grating and the eye-piece
to be increased in order to get distinct images, while before
necessary to diminish it. From this it was evident that
accuracy in the position of the images was due to the
g.

First of all the question was to determine the true form of
al curve that passes through the centre of curvature of the
g. According to Professor Rowland's theory this ought
circle, which should have as a diameter the straight line
nites the centre of curvature with the apex of the grating.
form of the curve differed perceptibly from a circle, it
not be possible with these gratings to obtain spectra of a
n scale.

form of the focal curve can be determined with the greatest
, if the apparatus is altered in such a manner that the slit
e movable along the rail that carries the grating.

$_1$G$_2$ (Fig. 1) be the grating, C its apex, O its centre of curv-
CLOM the theoretical focal circle, CL$_1$O$_1$OM$_1$ the true focal
hat passes through O, L the slit in its original place at the
of the right angle which is formed by the rails LC and LO.
on displacing the slit along LC or its elongation to a cer-
oint L$_1$, it will always be possible to obtain distinct images

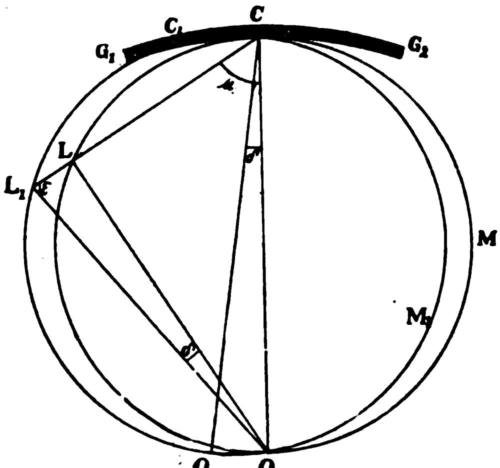

FIG. 1.

of the spectra, supposi in all cases that such c be given by the grati This point L_1 belongs the curve in questi whose polar coordina will be determined measuring the radius curvature CO (ρ), the c placement LL_1 (d), a the angle LCO (μ). I then, supposing d to positive, when the slit moved away from mirror, the radius vec $L_1C = r = \rho \cos \mu + d$ a the vectorial angle = ,

Denoting the wave-length by λ, the number of order of the sp trum by n, the distance between two adjacent lines of the grati by ω, we should have, if the theory were exact,

$$\sin \mu = \frac{\mathrm{LO}}{\rho} = \frac{n\lambda}{\omega}, \quad n\lambda = \frac{\omega}{\rho} . \mathrm{LO}.$$

To decide whether the same formula can be applied in the pres case, it will be sufficient to displace the slit along the rail LC a to observe if any change is produced in the spectrum, viz., if same value of μ always corresponds to the same value of λ dependently of the value of r. In reality small irregular var tions were found, which did not seem to exceed one of Angströn units, and which were doubtless due to imperfections in the ra and the adjustment. According to the theory of concave gr ings a difference of one Angström's unit in the spectrum cor sponds to a lateral displacement of the slit varying in the spec of different orders between 0.25 and 1 millim. Consequently formula is exact within the limits of error of our experiments. follows that the angle ε of the segment CL_1O is determined by equation

$$\cot \varepsilon = \frac{d}{\mathrm{LO}} = \frac{d\omega}{\rho \,.\, n\lambda}.$$

In this formula d and $n\lambda$ being the only variables, we see th it is sufficient that their quotient $\frac{d}{n\lambda}$ be constant, in order th the angle ε may be so too.

The measurements were executed in such a way that the scope was directed on some known line of the spectrum : movable carriage that bears the slit displaced along the , until a distinct image was obtained in O. The position of x, attached to the carriage, was read on a millimetre-scale the rail LC. Each of the numbers given in the following nder a_1 and a_2 is the mean of 10 of these readings, the careing alternately brought near to and removed from the . The column a_1 corresponds to the spectra on one side of ting, the column a_2 to those on the other; a greater value a greater distance from the grating. It was found that could be displaced through the space of about one milliithout it being possible to distinguish any variation in the on of the image. The probable errors of the means amount al to 0.2 millim., they never exceed 0.4 millim. Using as e of light sometimes the Sun, sometimes the voltaic arc, I l the spectroscope in the spectra of the first four orders to ak lines between D_1 and D_2 ($\lambda = 5893$) and to the double and b_4 of the solar spectrum or the strong doublets of the ring band of carbon (λ about 5165):

Wave-length $10^7\ n\lambda$	a_1	a_2	$\frac{1}{2}(a_1+a_2)$	Observed.		Calculated.
				d_1	d_2	d
1 × 5165	133.8	153.8	143.8	− 10.0	+ 10.0	9.4
1 × 5893	133 4	155.6	144.5	− 10.4	+ 11.8	10.8
2 × 5165	123.2	161.7	142.5	− 20.6	+ 17.9	18.9
2 × 5893	121.8	165.2	143.5	− 22.0	+ 21.4	21.5
3 × 5165	115.8	171.6	143.7	− 28.0	+ 27.8	28.3
3 × 5893	112.0	175.7	143.8	− 31.8	+ 31.9	37.7
4 × 5165	106.0	181.6	143.8	− 37.8	+ 37.8	32.3
4 × 5893	101.4	187.6	144.5	− 42.4	+ 43 8	43.0

Mean 143.8

rst column contains the number of order of the spectrum line to which the spectroscope was directed; the second roximate wave-length. In the fifth column are the means alues of a_1 and a_2, which correspond to the same line in ctra on the two opposite sides of the grating. These approach, as we see, to a constant value 143.8, which corls evidently to the normal position of the slit at the vertex ight angle formed by the rails. On determining by direct ements this position, I have found 144.8 ± 0.1. But the difference of one millimetre between the two numbers is perf explained through the uncertainty in the two adjustments o centre of curvature of the mirror on the axis of the carria the eye-piece, first in the direction of the girder that unites two carriages, and secondly, in the lateral direction. Of t have convinced myself by another series of determinations displacing intentionally the centre of curvature. A fault o millim. in the determination of the radius of curvature is cient to explain the before-mentioned difference.

Thus the point 143.8 is to be considered as the vertex o right angle of the rails, through which passes in the present the theoretical focal circle of the grating, or rather a curve w differs from it very slightly. Using this number (a_0) I have c lated the differences $d_1 = a_1 - a_0$ and $d_2 = a_2 - a_0$, which are f in the table under the heading "observed." A glance at t numbers shows that they are at least very nearly proportion the corresponding values of $n\lambda$, which implies that the angle the segment of the true focal curve is constant. To examine more closely, we will insert in the preceding equation of ϵ

$$\frac{\rho \cot \epsilon}{\omega} = x,$$

and we will calculate by the method of least squares the e value of x from the 16 equations of the form

$$x \,.\, n\lambda = d,$$

which we obtain from the preceding table by using all the va of d_1 and d_2.

In this way we find the value

$$x = \frac{\rho \cot \epsilon}{\omega} = 18261 \pm 80.$$

The numerically equal values of d_1 and d_2, which are obtaine making use of this value of x, are given under d in the last col of the table. The differences between these numbers and the served values being confined within the limits of errors of obs ation, it must be considered as proved that *the angle ϵ in the ment of the focal curve is a constant.*

A segment of which the angle is a constant belonging neces ily to a circle, we can express the result of our researches as lows:—

The focal curve which passes through the centre of curvatu the mirror is a circle, which, however, has not the radius of c ature in the apex of the grating as a diameter.

Always supposing, as in the preceding, that this curve hrough C, we see on fig. 1 where CO_1 is a diameter of the l circle, that the angle between CO and CO_1 is $= \delta = \frac{\pi}{2} - \varepsilon$. then

$$\tan \delta = \cot \varepsilon = 18261 \frac{\omega}{\rho}.$$

termination of the radius of curvature has given

$$\rho = 6434 \pm 1 \text{ millim.}$$

g to the statement engraved on the grating, $\omega = 0.0001$ .0254 millim. From this we obtain $\delta = 24' \, 47''$ and the $= \rho \tan \delta = 18261 \, \omega = 46.4$ millim. The difference be- e diameters CO and CO_1 amounts to 0.17 millim.

hough there could be no doubt as to the obliquity of the it was possible that we had to do with some accidental peculiar to our special grating. For that reason it was interest for me to find an opportunity to examine an- ating of the same kind, and this has been made possible the kindness of Dr. A. E. Andersson at Kristianstad, who good enough to place at my disposal a concave Row- ting of exactly the same kind as the preceding.

easurements, which have been executed in the same order e, follow here:—

Wave-length $10^7\, n\lambda$	a_1	a_2	$\frac{1}{2}(a_1+a_2)$	Observed.		Calculated.
				d_1	d_2	d
1 × 5165	130.3	155.6	143.0	− 12.3	+ 13.0	11.6
1 × 5893	129.2	158.5	143.9	− 13.4	+ 15.9	13.2
2 × 5165	118.3	164.6	141.5	− 24.3	+ 22.0	23.2
2 × 5893	115.5	168.7	142.1	− 27.1	+ 26.1	26.4
3 × 5165	108.6	177.4	143.0	− 34.0	+ 34.8	34.8
3 × 5893	104.2	181.1	142.7	− 38.4	+ 38.5	39.7
4 × 5165	95.5	189.6	142.5	− 47.1	+ 47.0	46.4
4 × 5893	89.7	195.3	142.5	− 52.9	+ 52.7	52.9
			Mean 142.6			

obable errors of the values of *a* are a little greater than receding case, and amount in maximum to 0.5 millim. er the adjustments of the grating are not of quite the actitude, owing to the limited time I had at my disposal ing these determinations. Hence there is nothing aston- the fact that the mean, 142.6, of the values of *a* differs a re from the normal value, 144.8, than is the case with

the other grating. The error necessary to produce such a d
ence does not exceed $\frac{1}{6000}$ of the distance to be determined.

On calculating as before the quotients $\frac{d}{n\lambda}$, we obtain

$$\frac{\rho \cot \varepsilon}{\omega} = 22440 \pm 120.$$

The radius of curvature of this grating was found to be
millim. greater than that of the other, viz., 6474 millim., th
certainty amounting to about 2 millim. With this value of ρ
the nominal value of ω we find $\delta = 30' 16''$ and $OO_1 = 57.0$ m
To judge from the inscriptions on the gratings the oblic
ought to have the same direction in both cases.

V. The focal curve that passes through the centre of curva
of the grating being a circle, as shown above, it will alwa
possible to adjust the spectroscope in such a manner as to ol
in all positions distinct images of the spectra without alt
the distance between the grating and the eyepiece. It fol
from the preceding that this is effected by causing the gird
act the part of the diameter O_1C of the true focal circle inste
that of a radius of curvature of the grating. Hence in the
grating the girder ought to be lengthened by 0.17 millim.,
turned round the point C through an angle $\delta = 24' 47''$.
easiest way of doing this is to displace the cross hairs of th
piece in O with the micrometer through a distance equal t
corresponding arc 46.4 millim. (to left or to right accor
to the side of the grating which we wish to make use of),
afterwards turning the grating until the cross hairs and
image coincide again. Then in all positions of the girder th
ought to remain on the true focal circle. The exactitude o
theory and the measurements is confirmed by the fact that
the execution of these adjustments the image became perfectl
fined through the whole spectrum.

It would also be possible to obtain distinct images in all
tions by another method, viz., by altering the angle of the
by a quantity δ. In that case the centre of curvature ough
to be displaced, but it is necessary to turn the micrometer
the photographic box through an angle δ, so that they ma
always tangents of the focal circle.

However, the supposition which we have made, that the
focal circle passes through the apex C of the grating, does
possess any very high degree of probability, because in that
the curve would intersect the surface of the grating. It s
more likely that it touches it, but at another point, which, as

s seen by construction and calculation, would be situated at a stance of 46.4 millim. from the apex C. In reality, the conclu- on, that could be drawn from the measurements would remain most the same, if we had replaced in fig. 1 the circle $CL_1O_1OM_1$ a circle passing through O but not through C or O_1 and touch- g the grating at C_1. This circle would have a radius equal to ρ, at is to say 0.17 millim. less than that of the former. As to e variation $\Delta\delta$ of the angle δ, we find $\sin \Delta\delta = \frac{\sin^2\delta}{2 \cos \mu}$, a antity varying with μ, but which falls within the limits of rors of observation in all parts of the spectra, that we can use. ne arc CC_1 differs from the arc OO_1 (46.4 millim.) only by some nth of a millimetre. Under this new supposition an exact ad- stment according to Professor Rowland's theory is obtained by splacing the grating 46.4 millim. along its own surface, until e point of contact of the focal circle falls in with the axis of the rriage, where the apex of the grating was situated before. The nsiderable obliquity that the position of the grating would ow in that case is the only difficulty with this arrangement. ence I have preferred the first method of adjustment, after hav- g convinced myself that the difference is of no importance from practical point of view.

VI. On the other hand, the last manner of considering the atter seems to possess a considerable advantage, because it will low us to account in a simple way for the relations between the ue focal circle and the grating. In reality, the accordance with rofessor Rowland's theory is perfect and the obliquity is only ie to the point of symmetry of the grating not coinciding with e apex of the concave mirror.

Let AC_1CBO (Fig. 2) be a section through the centre of curva- ire, perpendicular to the surface ACB and to the lines of the ating. Let AB be the chord of the section, which is perpendicu- r to the radius CO that passes through the apex of the spheri- l cap. The lines of the grating being drawn perpendicular to ie axis of the dividing-machine (and perpendicular according to ir supposition to the plane of the paper) it will always be pos- ble to draw in the plane of the paper a straight line EF parallel the axis in question. On a tangent plane TT_1 to the spherical irface, parallel to EF and perpendicular to the plane of the aper, the dividing-machine would draw equidistant lines. On oth sides of the point of contact C_1 of this plane the distances f the corresponding lines are also equal, C_1 is the point of sym- ietry and the point of contact of the focal circle.

Then it is immediately seen by the figure that the angle which is formed by the straight lines AB and EF becomes equal to the angle δ between the radii CO and C_1O. AB being = 150 millim. the values of the differences between AE and BF in the two gratings are found to be 1.08 and 1.32 millim. respectively.

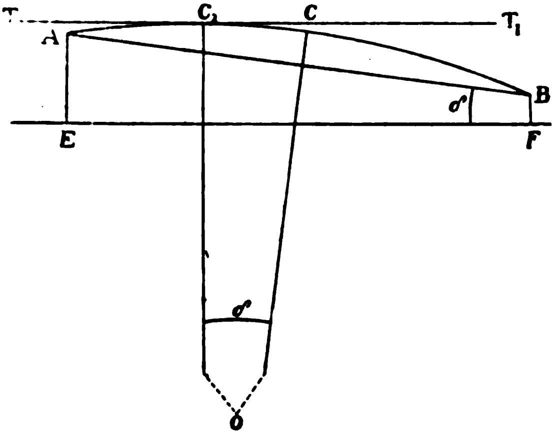

FIG. 2.

In this way the asymmetry of the gratings is explained in a manner as simple as it is complete. However, the differences found being much greater than would be supposed in a work of such perfection as are the gratings of Professor Rowland, we cannot exclude another hypothesis, the same that M. Cornu* has made use of in order to explain the focal properties of plane gratings, viz., a systematic variation in the distances of the lines. Such a variation would arise from an irregularity in the screw of the dividing machine, and in the plane gratings this explanation seems to be the only one possible. But in the concave gratings the same fault might also arise from another cause. The two sides of the gratings giving spectra of different brightness, we may conclude that the furrows which the point of the diamond makes in the reflecting surface are not symmetrical in section. Then it is easy to see that the distances of the lines are subject to a continual variation from one side of the grating to the other. But without knowing all the details of the work in the ruling of gratings, it would be useless to enter more closely into this hypothesis, and impossible to decide whether it is superior to the preceding.

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* *C. R.* lxxx. p. 645.

THE MAGNETIC STORM AND AURORAS OF JAN. 7 TO 10, 1886.[*]

M. A. VEEDER.

This period of auroras and magnetic disturbance, which was the iost prominent of any recorded during that month, affords the ieans of testing the question as to the location of the originating olar conditions in a very positive way. There was upon all the ates named a very extensive area of disturbance about ten de-rees south of the Sun's equator and at the eastern limb appear-ig by rotation. Although much disturbed, as evinced by the rilliance and extent of the faculæ, no spots formed in this area ntil its advance portions were on the meridian on the 12th, when here suddenly appeared a large spot which increased rapidly in ize, and was surrounded by numerous others upon the next two ays, when the group became of enormous extent. Here, if ever, he conditions were favorable for any effect proceeding from the ieridian, or just beyond, as Professor Ricco maintains in the Jan-ary number of ASTRONOMY AND ASTRO-PHYSICS as being the pos-ible rule. In spite, however, of the extraordinary character of his outbreak and its extremely rapid increase in the precise loca ion whence the meridian effect ought to proceed, there was not he faintest increase of magnetic perturbations, a few very slight nes only having been in progress on the days preceding. Nor vas there any report of an aurora of any kind. On the contrary n January 16th and 17th all magnetic disturbance ceased and bsolutely smooth curves were traced for the only time during he entire month for so long a period. Contrast this behavior vith the violence of the perturbations when the same area was t the eastern limb, and when it had not yet developed spots, nd the difference is most strikingly manifest.

If this case stood alone it would be sufficient to discredit the heory that the inductive effect proceeds from the Sun's meri-lian. On the other hand its bearing upon the view that such ffect proceeds from the eastern limb is equally plain, and is pecially instructive because of its showing that not faculæ in eneral, but faculæ preceding the formation of spots, and re-urring again and again in parts of the Sun frequented by pots are capable of exercising the auroral and magnetic effect. The writer had supposed that this had been made so plain in revious notes and articles that there could be no mistake. Inasmuch, however, as misapprehensions of one sort or another

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[*] Communicated by the author.

are found to exist he is preparing to submit the evidence in detail that will show that cases such as that above described are not simply common, but follow an absolute rule, exceptions to which, if they exist at all, are very difficult to find.

LYONS, N. Y., April 14, 1893.

SPECTROSCOPIC NOTES FROM THE KENWOOD OBSERVATORY.*

GEORGE E. HALE.

THE SOLAR PROMINENCES AND FACULÆ OF APRIL 16, 1893.

The accompanying plate represents the prominences and faculae photographed at Chicago with the spectroheliograph at about the time of the total phase in South America of the solar eclipse.† The drawing was made from the original negatives by projecting on a screen of white paper with an optical lantern, and tracing the forms of the prominences and faculae. By this method it is possible to bring out faint details which would be lost in a direct photographic reproduction of the original negatives, at the same time preserving absolute truthfulness of form in the representation.‡

In spite of the fact that the sky was very white when the photographs were taken, both prominences and faculae are fairly well shown. As is the case in all "spectroheliograms," no details are visible in the spots, the smaller spots and the penumbrae of the larger ones being concealed by overlying faculae.§ The greatest solar activity is clearly in the southern hemisphere, where both faculae and prominences are more numerous than in northern. As this has prevailed for some time it would be natural to expect a corresponding development of the corona south of the equator. The long chain of prominences in the southwest quadrant is a noticeable feature of the photographs. It was photographed on April 15th and differed but little in form except by the absence of the two streamers which were of later origin. On April 17th this prominence had greatly decreased in size.

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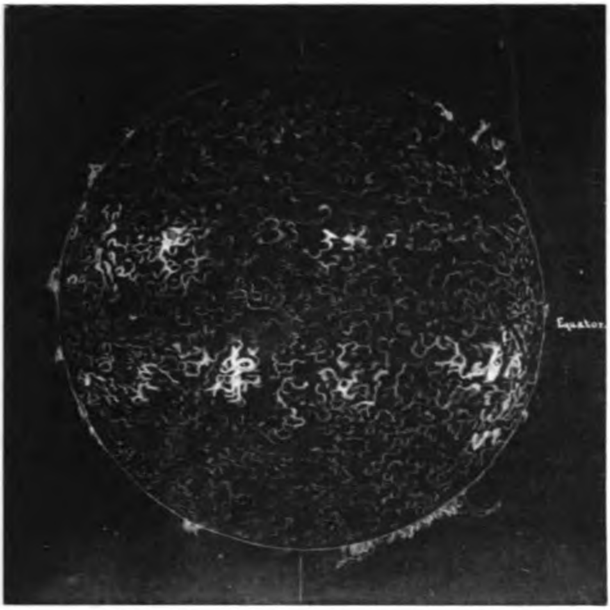
* Communicated by the author.

† The photographs used in making the illustration were four in number, two showing prominences and two faculæ. The former were taken at $9^h 15^m$ and $9^h 59^m$ A. M. and the latter at $9^h 0^m$ and $9^h 6^m$ A. M., Chicago M. T. Clouds prevented photographs being taken at the exact time of totality.

‡ The process of reproduction from the elliptical image of the original negatives was unfortunately not free from distortion. It will be noticed that the line representing the solar equator appears below the center of the image.

§ The positions of the spots on the figure are denoted by small crosses, but these will hardly be noticed without a magnifier.

PLATE XXV.



The Solar Prominences and Faculæ of April 16, 1893.

vill be of interest to compare these results with those obtainring the eclipse. Some light may perhaps be thrown on the nysterious "white prominences," and the complete record of culae may also be of value.

ON THE SIZE AND DISTRIBUTION OF SOLAR FACULÆ.

recent photographic work with the spectroheliograph the d slit has been made very narrow and a piece of blue glass een held over the first slit during the exposure. The advanin photographing the faculae is very marked, as the greater of the green region in the overlapping spectrum of the third , which before fell on the photographic plate during the exre, is now cut out. An examination of the absorption spec- of the glass shows that the green is only partly absorbed, vith a better quality of glass it will no doubt be possible to urther improve the photographs.

ave elsewhere remarked on the great size and extent of the ae as shown on photographs taken with the spectroheliob. The negatives made with the blue glass absorbant, how- show that my estimates have been even too small. Faculæ rto invisible are now seen dotting the surface of the Sun pole to pole. These faint faculæ do not appear to be separnd independent phenomena; over the whole surface of the hey seem to be connected like the meshes of a net, though the s of the enclosed spaces are very irregular. Between lati- + 40 and − 40 they are somewhat brighter than in the re- near the poles, and on the best photographs connecting ps can be traced for great distances. Some of these will be ed on the accompanying plate, though the photographs h it represents were made under unfavorable atmospheric itions, and do not bring out the faintest faculæ.

e greater part of these faint objects are quite invisible to the n telescopic observation, but they are probably identical the small irregular reversals of the C line noticed when the of a solar spectroscope is moved across the Sun's image. tographs taken here in December, 1891, showed that the reals of the H and K lines were almost unbroken on the solar ace*, but hitherto the faintest of these regions have escaped pectroheliograph. Though they seem to form a nearly conous net-work they are of course not to be confused with M. sen's *reseau photospherique.*

Father Sidgreaves has remarked such continuous reversals on photographs ot spectra taken at Stonyhurst.—*Monthly Notices*, February, 1893.

Between these faint objects and the brightest faculæ, we find faculæ of every intermediate degree of brilliancy; sometimes a single photograph shows faculæ representing almost all the gradations of brightness. Groups of faculæ are at present (April 14) so numerous in the southern spot zone that they form an almost unbroken belt across the Sun parallel to the equator. One is led to ask whether such belts may not in the future become continuous—or are the indications those of a past condition of the Sun's life?

The curved forms of the faculæ, to which I have referred in previous papers, are frequently so marked that one can hardly doubt the evidence of cyclonic motion. The small size of the solar image in our present photographs makes an investigation of this subject somewhat difficult, but I hope to take it up soon with the 40-inch Yerkes telescope.

THE H AND K LINES IN THE CALCIUM SPECTRUM.

In the winter of 1890-91, while engaged in a study of the ultraviolet spectrum of burning magnesium ribbon, I detected on the photographs what appeared to be faint traces of the H and K lines of calcium. As these lines had never to my knowledge been obtained in the laboratory without electrical means, it was decided to investigate their seeming presence in the flame. To this end a large number of photographs were made, and the presence of the lines in the spectrum of burning magnesium ribbon, which had been passed through a solution of calcium chloride, was clearly established. In the fourth order spectrum of a concave grating (14,438 lines to the inch) of ten feet radius, the lines thus produced in the flame coincided absolutely with the H and K lines in the calcium spark. In the flame, however, the lines were so faint that they required an exposure of two hours, while a few minutes sufficed for the spark. The blue line at λ 4226.9, which is strong in the flame, is far less prominent in the spark.

The subject has recently been taken up at the Kenwood Observatory by Mr. S. B. Barrett, a graduate student in astro-physics at the University of Chicago. Since my laboratory work in 1890 much has been learned of the H and K lines in solar and stellar spectra, and Mr. Barrett has undertaken to continue the study in terrestrial sources of heat. He has confirmed the results obtained with the magnesium flame, and has also found both of the lines in the oxy-coal-gas flame. In the blast-flame and Bunsen burner they have not been certainly detected, though with the latter an exposure of over 100 hours was given, the flame being fed continuously by a wheel of platinum wire rotating by clockwork through a solution of calcium chloride. The solution is kept at a proper level in the tank by an automatic siphon. This little device of Mr. Barrett's is very useful for long exposures.

From the oxy-coal-gas flame to the prominences the H and K lines preserve the same relative intensity, K being invariably stronger than H. The following table is given to make evident the wide distribution of calcium, and the importance of exhaustively investigating its spectrum. The character of the lines was in all cases determined from photographs taken at the Kenwood Observatory.

Light Source.	*Character of H and K lines.*
Bunsen flame	Presence uncertain.
Blast flame	Presence uncertain.
Oxy-coal-gas flame	Faint, narrow, sharp.
Magnesium flame	Faint, narrow, sharp.
Electric arc	Strong, broad, hazy, reversed.
Electric spark	Strong, narrow, sharp.
Sun (general spectrum)	Very broad, hazy, dark bands; narrow dark line in center. Most prominent lines in spectrum.
Sun-spots	Bright, narrow, sharp in umbra; doubly reversed in penumbra. Strongest lines in spectrum.
Faculæ	Narrow, sharp, doubly reversed. Strongest lines in spectrum.
Chromosphere	Narrow, sharp, often doubly reversed; strongest lines in spectrum.
Prominences	Bright, narrower than in chromosphere, sharp, rarely doubly reversed; strongest and longest lines in spectrum.
α Lyræ	K dark, narrow; H masked by hydrogen ϵ line.

Many questions of interest from both physical and astronomical standpoints are involved in the investigation, and these will be discussed in a future paper.

A METHOD OF STUDYING THE DISTRIBUTION OF METALLIC VAPORS IN THE ELECTRIC ARC.

A careful study of the spectroheliograph has convinced me that this instrument, although primarily designed for photographing the solar prominences and faculæ, may have wider applications. To its possible employment for photographing the solar corona without an eclipse, I have referred in the last number of this journal. Experiments in this direction are now in progress at the Kenwood Observatory, but up to the present time the sky has shown so much whiteness from the city smoke, as well as from dust carried to great elevations by exceptionally high winds, that we have had to content ourselves with completing the adjustments of the apparatus, which is attached to the 12-inch equatorial. We can hardly hope under any circumstances to successfully photograph the corona in the heart of a smoky city, but I am fully convinced that some success would be attained if the method were tried from such an elevation as Pike's Peak. The method here referred to is that outlined in the last number of this journal—the reduction of the diffuse light of the sky near the Sun by setting the broad dark K band of the sky spectrum on the second slit of the spectroheliograph.

Still another use of the spectroheliograph—this time for laboratory purposes—has suggested itself. It is well known that the distribution of vapors in the electric arc is by no means uniform—different parts of the arc give different spectra. An excellent method of investigating the distribution would be to photograph the arc with a spectroheliograph, using successively different lines of the spectrum. The peculiarities of distribution about the positive and negative poles and in the flame, as well as the separation of different vapors, could thus be made manifest.

AN ERUPTION ON THE SUN'S SURFACE.

"Spectroheliograms" taken on Jan. 26, 1893, give a complete history of an eruption which occurred near the solar equator on the northern edge of a large group of spots and faculæ which a few days before had come into view at the eastern limb. The eruption was not unlike that photographed at the Kenwood Observatory on July 15, 1892, though it was less brilliant and on a smaller scale. The first indications of the outburst are seen in a spectroheliogram taken at 10^h 25^m (Chicago M. T.), and at 10^h 42^m the disturbance was at its maximum. At 11^h 17^m the mass of erupted matter had greatly decreased in brilliancy, and at 11^h 36^m it had disappeared. The eruption was not visible to the eye in an image of the Sun projected on a white surface by the eyepiece. I have not yet learned whether there was any accompanying magnetic disturbance.

ON THE HISTORY OF SOLAR PROMINENCE PHOTOGRAPHY.

In an article on the spectroheliograph in the March number of this journal I attributed to Dr. C. Braun, formerly director of the Haynald Observatory at Kalocsa, the credit of first pointing out the method upon which that instrument—itself devised independently in 1889—is based. This I now find to be a mistake. In the *Comptes rendus* for March 6, 1893, M. Janssen, after a very kind reference to the photographic results obtained at the Kenwood Observatory, shows that the principle of using a second slit and photographing the prominences by monochromatic light was discussed by him at the Exeter meeting of the British Association in 1869. I had not previously seen the note referred to, and I now hasten to acknowledge my error, as well as my indebtedness to M. Janssen for the correction.

Kenwood Observatory,
University of Chicago, April 17, 1893.

A PROPOSED METHOD OF DETERMINING WITH GREAT EXACTNESS THE INDEX OF REFRACTION AND THE DISPERSION OF AIR.[*]

B. HASSELBERG.

In the study of astronomical refraction as well as in various optical investigations a knowledge of the index of refraction of air for the different lines of the spectrum is well known to be of great importance. Numerous attempts to determine its value have been made since the beginning of the present century. In considering the different methods employed for this purpose one may divide them into two distinct classes, one of which, devised by Borda and employed for the first time by Arago and Biot[†] and later by Dulong[‡], is based on the direct measure of the deviation of a luminous ray through a prism from which the air has been exhausted, while the other, devised by Arago[§] and employed by Jamin[‖] and Ketteler[¶], is founded on the interference of two pencils of light, in one of which a suitable difference of path may be introduced. All of these investigations, with the exception of that of Ketteler, give only the mean index of refraction of air, but, as M. Mascart has recently shown, with a precision far from satisfactory.[**] The index of refraction obtained by M. Ketteler for the D line, having been determined by only two measures, does not seem to merit greater confidence than that which may be accorded to the values of Arago and Jamin, with which it is moreover almost identical. The indices of the other principal lines of the solar spectrum having been deduced from the first by an interpolation formula, are consequently subject to the same uncertainty as far as their absolute values are concerned; as for their

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[*] *K. Vetenskaps-Akademiens Forhandlingar*, 1892.
[†] *Memoires de l' Institut*, T. viii, p. 301, 1806.
[‡] *Annales de Chimie et de Physique*, 2 Sér., T. xxxi, p. 154.
[§] *Ann. de Chim. et de Phys.*, 2 Sér., T. i., p. 1.
[‖] *Ann. de Chim. et de Phys.*, 3 Sér., T. xlix, p. 282.
[¶] *Poggendorff's Annalen*, Bd. cxxiv. s. 390.
[**] *Annales de l'ecole normale*, 2 Sér., T. vi, p. 9-78, 1877.

relative values the precision is certainly greater, though in no case of the high order which the great number of decimals employed would seem to indicate.

In this condition of things the question has recently been taken up again by M. Mascart* in a much more profound and rigorous manner. His method is also that of light interference, but for the end in view he profits by a special kind of interference—Talbot's bands. A complete theory of these singular phenomena was long ago given by Airy†, but this theory being extremely complex M. Mascart substitutes for it another of much greater simplicity. After having, moreover, carefully studied all the circumstances which can in any way affect the exactness of the results to be obtained, M. Mascart finally arrives at the following value for the index of refraction of air at zero temperature and 76 cm. pressure, for the D line of the solar spectrum:

$$n = 1.0002927.$$

The exactness of this value is estimated by M. Mascart as within about 6 units in the last decimal place. It will also be noticed that the refraction of air is sensibly less than is indicated by the researches of Biot and Arago, the final result of which is:

$$n = 1.0002945.$$

By these investigations of M. Mascart the question of the refraction and also the dispersion of air might be considered as definitely solved. This may be true for the greater part of the applications of these constants in astronomy, in spectroscopy, etc.; nevertheless an independent confirmation by a different method capable of great precision does not seem wholly without interest. For this reason I venture to propose the following mode of procedure:

Everyone is aware of the truly extraordinary precision which may be arrived at in the determination of the relative position of two spectral lines on a good photographic negative obtained by means of Professor Rowland's large diffraction gratings. This circumstance leads me to believe that by combining the Borda prism with a large diffraction grating spectrograph one might succeed in measuring the deviations and consequently the indices of air with a very great precision, much higher than any yet attained. Suppose then that one has at disposal such a spectrograph, with a plane grating ruled in the ordinary way on a

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* *Loc. cit.*

† *Phil. Trans.*, 1840, Part II, and 1841, Part I.

surface 50 × 80 mm. with 14,400 lines to the English inch, and a collimator consisting of a refractor of 7 — 8 cm. aperture and 1.5 metres focal length. The objective of the camera should have the same aperture and a focal length of 2 metres.

The two tubes should be fixed with their optical axes making a constant angle of about 40°. The grating is placed on the horizontal circle of a theodolite in such a manner that its center line coincides with both the vertical axis of the circle and the point of intersection of the optical axes of the collimator and the camera. In this condition of things all the spectra may be brought into the field of view by turning the grating, and if the normal to the grating coincides with either of the optical axes the D line of the second order will be found in the field of view. Finally, the slit is provided with two small slides, by means of which the upper or lower half may be uncovered, so as to obtain on the photographic plate two juxtaposed images of the spectrum.

This having been arranged, and the slit being adjusted so that the rays issuing from the collimator are parallel, a Borda prism, filled with air at the same temperature and pressure as the surrounding air, is placed between the camera objective and the grating. Assuming that the glass faces of this prism are absolutely plane and everywhere of the same thickness, the interposition of the prism will influence neither the sharpness nor the position of a given spectral line. If now the air is exhausted from the prism the spectral line, while preserving its original sharpness, will be displaced toward one side or the other, according to the position of the prism, by an amount proportional to the refraction of air for the wave-length in question. By now turning the prism 180° the same displacement will take place, but in the opposite direction. The difference between the two positions of the line in these two positions of the prism will thus correspond to twice the deviation of the rays in passing through the evacuated prism. Supposing the angle of the prism to be 120°, and by the aid of the mean index of air $n = 1.000293$ the well known formula

$$n - 1 = \cot\frac{A}{2} \cdot \frac{\Delta}{2} \sin 1'' \quad (1)$$

gives for Δ the value

$$\Delta = 206''.$$

Thus the angular distance between the two positions of the line named above will be:

$$2\Delta = 412''.$$

To this angular distance corresponds in the focal plane of the camera of the spectrograph a linear distance

$$\delta = 4^{\text{mm}}$$

approximately. Such will therefore be the difference in position of two images of the line which will be obtained if in the two positions of the evacuated prism a photographic plate is exposed to the spectra formed by the upper and lower half of the slit of the collimator.

The numerous measures which I have had occasion to make on spectrograms of the same nature as those here in question have shown that the distance between two spectral lines may be measured on a good negative by means of a dividing engine with a probable error in general not greater than

$$\pm\, 0.002^{\text{mm}}.$$

Thus the distance between the two photographic images of the displaced line in the two positions of the prism may be determined with the same exactness, *i. e.* about $\frac{1}{2000}$ of its value. Thus the probable error of the double displacement 2Δ, in so far as it depends on measures of the plate, will be only about

$$\pm\, \tfrac{1}{2000} .400'' = \pm\, 0''.2$$

and consequently the probable error of the single displacement

$$d\Delta = 0''.1.$$

Differentiating equation (1) we find:

$$dn = \frac{1}{2} \cot \frac{A}{2} \,.\, d\Delta \,.\, \sin 1''$$

whence

$$dn = \pm\, 0.00000014.$$

Thus the probable error of the index of refraction of air for the observed line will not in general exceed *two units* in the seventh decimal place, *i. e.*, it will be three times smaller than the probable error which M. Mascart considers should be attributed to his final values.

I have assumed above that the slit should be placed exactly in the principal focus of the collimator for the special rays which form the line photographed. This would be necessary if one photographed in one case the undisplaced line, *i. e.* formed by the rays transmitted by the prism full of air, and in the other case the line displaced by the evacuated prism. In fact in these two cases the position of the focal plane of the camera would only be the same in case the rays emanating from the grating were parallel. But this identity of position of the focal plane for the two lines, displaced and undisplaced, is evidently quite necessary in order to have the images of the same sharpness in the two negatives taken with the two halves of the slit. Consequently, if it were desired to measure the single displacement it would be necessary to adjust the slit each time so that the rays corresponding to the line employed should leave the objective of the collimator sensibly parallel. In the method described above, on the contrary, where the double displacement is measured, and in which the evacuated prism is fixed during both exposures of the photographic plate, this condition is no longer necessary, since in this case the sharpness of the images of the line photographed depends solely on the condition that the plate be exactly in the conjugate focal plane of the collimator slit.

From the equation

$$\delta = F \tan 2\varDelta \doteq 2\,F\varDelta \,.\, \tan 1''$$

we obtain:

$$\frac{dF}{F} = \frac{-d\varDelta}{\varDelta}.$$

The condition

$$\frac{d\varDelta}{\varDelta} = \pm \frac{1}{2000}$$

therefore leads to the following:

$$\frac{dF}{F} = \mp \frac{1}{2000}$$

i. e., to reach the desired precision in the determination of the index of refraction the focal length of the camera objective must be known within $\frac{1}{2000}$ of its value, or in the present case to about 1^{mm}. But in employing Bessel's method for the determination of focal lengths with the modifications which I have described elsewhere[*] it is perfectly easy to satisfy this condition.

In addition to the quantities so far considered the absolute values of the required indices depend also on the temperature and pressure of the air which surrounds the prism. Denoting these quantities by t and H, and the index found directly and reduced to zero and 0.76^{m} by n and n_0, we have:

$$n_0 - 1 = (n - 1)\,(1 + \alpha t)\,.\,\frac{760}{H}.$$

Thus the correction which must be applied to $n - 1$ to obtain its value at zero and 0.76^{m} will be:

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[*] *Bulletin de l'Académie des Sciences de St. Petersbourg*, T. XXXII, p. 412.

$$C = (n-1)\left[(1+at)\frac{760}{H} - 1\right]$$

If the error resulting in the determination of t were 1°, the corresponding error of C would be

$$dC = 0.0000011$$

approximately, which indicates that in order to correspond to the desired precision of the determinations of the index the absolute value of the temperature must be known within about 0°.2. But this is a condition not difficult to satisfy, because during the two exposures of the plate, which require not more than one minute of time when the solar spectrum is used, the variations in the temperature of the air may be considered infinitely small.

As for the influence which an incorrect determination of the pressure of the air may have on the values of the indices of refraction, we readily find that this influence exceeds the prescribed limits only in case the error in H is greater than 0.5 mm., an error which may be easily avoided.*

Finally, there remains one further source of error to be considered, which at first sight seems the most serious of all—the prismatic form of the glass plates forming the prism in the direction of the plane of dispersion. Admitting the existence of such a defect it is easily seen that the deviation Δ found in the manner described above is the algebraic sum of the deviations caused by the refraction of the air and by that of the plates. To determine the direction of this last deviation as well as to determine its numerical value we may proceed in the same manner described above, but leaving the prism filled with air at the same temperature and pressure as the surrounding air; for then the displacements of the spectral line would depend only on the refraction in the plates. But instead of this it would evidently be better if by a suitable arrangement of the experiment the error could be eliminated without determining it. This would be possible if after having finished a series of measures the faces of the prism were removed and once more cemented in such a manner that the side formerly turned toward the base of the prism were now directed toward the top and vice versa. Thus the direction of the refraction by the plates is reversed and if the deviations obtained in the first series were for example too great, a second series of measures would give values too small by the same amount, so that the mean of the two series would be freed from the error arising from the prismatic form of the plates.

The considerations presented above will suffice, I believe, to indicate the exceptional precision of which the method in question is susceptible. In this connection two circumstances merit special attention as serving to remove the disturbances due to variations of temperature, the injurious effect of which one can never be sure of having avoided in the first form of the method. In fact, the prism having once been evacuated, all further action of the air-pump is without effect, and consequently all variations of temperature in the prism due to rarefaction and compression of the air will be eliminated. In the second place the time of about one minute necessary for the exposure of the photographic plate in the two positions of the prism is so short that the temperature of the surrounding air may be considered as sensibly constant during this interval. These advantages combined with the precision of spectrographic measures should suffice to assure to the values of the indices of refraction the exactness desired.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Total Eclipse of April 16.—The following telegrams are from the Chicago *Tribune:*

VALPARAISO, April 16.—Observations of the total solar eclipse were taken today at Mina Aris, Harvard College Station. The weather was clear during all phases of the eclipse, with no passing cloud and no haze to mar the observation. Atmospheric conditions were all that could have been wished for, and the results will be satisfactory to the highest degree.

The corona, seen this morning, generally speaking, resembled the corona of 1871, as portrayed by Capt. Tupman, and complex, like that observed by Liais in 1857, which extended some 700,000 miles from the Sun. There were four streamers, two of which have a length exceeding the Sun's radius, or stretching out more than 435,000 miles. Several dark rifts were visible, extending directly outward from the Moon's limb to the utmost limit of the corona. Filaments were numerous about both the solar poles. Compared with the corona of Jan. 1, 1889, the corona just observed was more brilliant.

During the total eclipse today several flaming solar prominences attained great distinctness and brilliancy. Within the streamers no rapid movements were observed, but the impression of the scene was rather one of calm and tranquillity. The streamers were widely extended at the base, but not very long. The Moon appeared of almost inky darkness, with only enough illumination at the edge of the disk to make its rotundity conspicuous, while from behind the orb streamed out on all sides the radiant filaments, beams, and sheets of pearly light which formed an irregular star-like decoration with a black lunar globe in its center.

The inner corona was of dazzling brightness, but still more dazzling were the eruptive prominences which blazed through it, to use the words of Professor Young, "like carbuncles."

Generally the inner corona had quite a uniform altitude, forming a ring about four minutes of arc in width, but separated with more or less definiteness from the outer corona, which projected to a far greater distance and was much more irregular in shape. During totality the distinctness and brilliancy of several prominences were pronounced. One of these was 80,000 miles in height. The spectroscopic observations secured today are very promising. As the eclipse progressed the temperature of the air fell considerably below its normal. The lowest reading of the thermometer occurred several minutes after totality.

To be more explicit the outer corona was unequally extended and much larger than in 1879 or 1889, as was to have been expected during the present period of increasing solar activity. The eclipse observations showed conclusively that the Sun is now far from being quiescent, but is in a state of great disturbance. There was very distinct evidence of great spottedness and the presence of faculæ or bright torch-like streaks. The color of the corona was rather whitish than red and of a pale or pearly white hue. Upon review of all today's observations, it may be said that the corona was a confirmation of that of 1871 and that of 1857, as drawn by Liais. The photographs of the eclipse obtained at Mina Aris were numerous and satisfactory. PICKERING.

LONDON, April 16.—A dispatch from Bathurst, British Gambia, states that the British astronomers at the station on the Salum River in French Senegambia obtained fine observations of the eclipse of the Sun today.

VALPARAISO, April 19.—Professor Schaeberle sends the following account of his observations at Mina Bronces of the total solar eclipse:

Sunday was a pleasant day for viewing the eclipse. The corona was very brilliant and much extended in all directions. It was similar to the corona of the eclipse of 1883. Eight photographs 10 × 20 inches in size, were obtained with the heliograph, and ten photographs were secured with the six-foot telescope and the same number with the three-foot telescope. I also obtained six photographs with the one-foot telescope and seventeen camera photographs with the forty-foot glass. These photographs demonstrate enormous prominences and also show solar clouds nearly 100,000 miles in height floating through space. The polar rays and others were long, conspicuous and trumpet-shaped in outline. The outer corona was prominent. The preliminary results are a strong confirmation of my mechanical theory of the corona. I received valuable help from various persons, especially from King Gale.

VALPARAISO, April 18.—Professor Pickering has worked out some of his observations. Forty minutes after the first contact, about three minutes to 8 A. M., the light of the Sun was observed changing to a sickly yellow hue, and there was a perceptible, though faint, chill of the air. Twenty minutes later the corona was revealed around the Moon before the obscuration had become total. During the period of totality there were in the east and west dark tints like rain clouds lowering on the horizon. The colors were yellow and faint orange in general, the light resembling that of a faint dawn. But generally it was less dark than at past eclipses. Professor Obrecht took observations 900 feet higher than Professor Pickering. His data were scant, having been obtained only through the telescope. The temperature fell three degrees during totality. This was specially notable, the observer considers. The shadow-bands, or "fringes," were similar to hot air waves over an oven or ripples on a pond, having the velocity of a fast walk. None of them were more than two inches in length. They were from one to three feet apart. They were seen before and after totality; before totality they were faint. The directions of movement were variable.

Professor Pickering says the results obtained with the differential spectroscope give twenty lines in the "reversing layer" of the solar atmosphere—the shallow stratum of gas lying just above the photosphere and known to contain the vapors of many elements commonly found on our globe. Twelve of these brilliant colored spectral lines were seen through the telescope. This is the first time that these lines have been successfully photographed. Professor Pickering also says that the entire spectroscopic and corona photographs taken Sunday are very satisfactory and promise to yield important data. Thirty-four seconds before the eclipse became total two rays of light issuing from the cusps were observed in violent motion. Before totality the corona showed a conical structure, with a network of fine filaments visible to the naked eye. There were four light streamers from the corona; the two upper were shorter than the lower ones. Seven prominences were observed. Douglass estimates that they attained a height of 80,000 miles. The expedition is satisfied with the photometric results. Photographs taken with a double image prism were secured.

LICK OBSERVATORY, MOUNT HAMILTON Cal., April 18.—A cipher telegram just received from Professor Schæberle in Chile brings information that the Lick Observatory expedition to observe the total solar eclipse has been successful in every respect. The mechanical theory of the solar corona, proposed by Professor Schæberle, has been verified. His telegram means that the picture made by him months ago was a true representation of the actual corona visible at the eclipse. This is an important verification of the very far-reaching theory. The expansion of the solar corona was first photographed at the California eclipse of Jan. 1, 1889, and was fully described in the Lick Observatory report of that eclipse. Its existence was doubted by various European astronomers, and the cloudy weather did not allow it to be plainly photographed at the eclipse of December, 1889. Now, however, Professor Schæberle telegraphs that it has been again sucessfully photographed at his station high up in the mountains. Fifty photographs have been secured by Professor Schæberle and his assistants, using three different telescopes. One of these instruments gives an image of the Sun four inches in diameter and the corona covers a plate 18x22 inches. The whole program was satisfactorily carried out. It is only proper to add that the expenses of the Lick Observatory expedition were generously provided for by a gift from Mrs. Hearst of California, to whom science owes a new debt.

The Absorption of Heat in the Solar Atmosphere is the title of a valuable paper read before the Royal Irish Academy on May 9, 1892, by Messrs. W. E. Wilson and A. A. Rambaut.

The experimental part of the research has been performed by Mr. Wilson, while Dr. Rambaut has supplied the carefully developed mathematical theory.

The method consists[*] in allowing a large image (80 cm. diam.) of the Sun, produced by a heliostat and concave mirror of 10 ft. focus, to drift across the face (2 mm. square) of a Boys' radio-micrometer. The deflection is recorded photographically, and seconds are automatically marked off on the curve by a pendulum.

The differential equations for the motion of the needle are given, as well as the methods of determining the constants of the equations.

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[*] Wilson. This Journal, 1892, p. 49.

The process of making an observation is certainly very simple, though the subsequent reduction would become a trifle tedious. It would appear quite desirable to determine the constants frequently.

The intention is expressed of continuing these observations with considerable regularity throughout the eleven year period of solar activity. Such a work cannot fail to be of high value in the solution of some of the outstanding solar problems.

In the present paper numerical results are given for only two transits, on different days, so that it is difficult to compare the accuracy attained with that of other recent observations* upon this subject. From the differences between the values obtained along the eastern and western radii of the Sun the degree of accuracy would appear to be about the same as for those cited, and the absolute values do not greatly differ.

The disadvantages of the method are that it does not, in the arrangement described in this paper, permit of observations of the northern and southern hemisperes of the Sun, nor continuously of the true eastern and western extremities of the solar equator.

If the transit is not exactly central it cannot be utilized so as to be absolutely independent of previous central transits.

It would seem desirable to have a means of inverting the solar image so that the same should side alternately transit first and last.

It would also be advantageous for the observer to be able to follow the image as it drifts across, and thus assure himself whether casual irregularities were due to faculae visibly present on the disc. Perhaps this would be equally well attained by having a careful drawing or photograph (or best of all a "spectroheliogram") of the Sun made at the same time with the observed "thermal transit."

It is to be hoped that the instrument will also be directed to the study of the faculae and Sun-spots, where the photographic registry could perhaps be well dispensed with.

The paper concludes with a provisional—because dependent upon so few observational data—determination of the total absorption in the solar atmosphere. The modified Laplace formula is used, as well as his solution of the integral by a continued fraction.

The results do not materially differ from those already alluded to which depend upon many more observations. Further results of Mr. Wilson's work will be awaited with interest. F.

Examination of Photographic Lenses at Kew.—Major Darwin's report on the examination of photographic lenses at the Kew Observatory (Royal Society Proceedings, No. 318, p. 403,) contains much valuable information on the characteristic qualities of the various kinds of lenses, and may be recommended for perusal by the intelligent photographer in place of the frequently grossly incorrect "photographic optics" of the ordinary text book or "photographic instructor."

The object of the committee represented by Major Darwin was to devise a method for the rapid examination of photographic lenses sent to the observatory, with a view to issuing certificates on the payment of a small fee. Beside data obtained by inspection or by comparatively simple measurement, the statements of the certificate relate chiefly to the following qualities: curvature of the field, definition at the center with the largest stop, distortion, achromatism, astigmatism, and illumination of the field at different distances from the center. On account of

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* Frost. This Journal, 1892, p. 720.

the necessity for keeping the expense as low as possible, all observations are made by visual methods which are fully explained in the report, and which seem to be unexceptionable.

Major Darwin considers that the most serious omission in the Kew examination is, that there is nothing to show the actinic transparency of the glass, as a slight yellow tinge in the lenses, which would not be noticed by the eye, might yet be sufficient to seriously affect the rapidity of the objective. It does not seem to us that a selective absorption insufficient to produce a yellow tinge that could be detected by the eye, would be appreciable in the photographically active part of the spectrum, which is practically included between λ 4000 and λ 4860.

On the History of the Bolometer.—Recent German experimenters have described a supposed new method of obtaining the very thin strips of platinum used in the bolometer, which is essentially as follows: a strip of platinum is placed on a thicker one of silver, the two are welded together, rolled out to any desired extent, and the silver backing is then dissolved away by nitric acid. Priority in such a detail as this is of no special consequence, but as a matter of fact, Professor Langley has employed this method since 1881, with the slight difference that copper is used as a backing instead of silver. No doubt the method was suggested by the early experiments of Wallaston in drawing fine platinum wire by an analagous process.

In connection with the bolometer may be mentioned some very small galvanometer mirrors recently made by Mr. Brashear for the Smithsonian Institution, as their construction involves some rather curious points in optical practice. The mirrors were required to have a diameter of 2½ millimetres, an accurately spherical figure with radius of one metre, and not to exceed in weight 3¼ milligrammes or one twentieth grain. The method first tried was to grind and properly figure one side of a little glass disc thick enough to retain its shape, and subsequently to reduce the thickness by grinding away the back until the desired weight was reached, but it was found that the mirror curled up at the edges on the concave side, so as to come out with a much shorter radius than that required. Experiment showed finally that it was necessary to start with a radius of 3.2 metres in order to have the radius come out one metre after grinding away the back of the glass, and as the mirrors were seldom considerate enough to preserve a spherical figure in the process of curling, a great many of them had to be made, in order to procure a few which came within the requirements. A large number were ground together, after the manner of spectacle lenses.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR JUNE.

Mercury will be at superior conjunction at $10^h\ 30^m$ A. M. June 4, and will not be in position for naked-eye observations during this month. It may be possible to obtain telescopic views of the planet during the afternoon in the latter half of the month. Mercury will be in conjunction with Venus, 59′ north, June 14 at $8^h\ 39^m$ P. M. central time. There will also be a conjunction of Mercury and Mars June 27 at $10^h\ 19^m$ A. M., Mercury passing 25′ north of Mars.

Venus will be "evening star" during June, but will be too near the Sun for favorable observations. She will be in conjunction with the crescent Moon, 3° 52′ south, June 14 at $7^h\ 21^m$ P. M. The three celestial bodies, Mercury, Venus, and the Moon, will be quite near together on that evening.

Mars will be a little higher in the heavens than Venus, but will be overtaken by Mercury June 27. The distance of Mars from the Earth on June 15 will be about 231,000,000 miles. The apparent diameter of the planet will then be only $4''$.

Jupiter has passed behind the Sun, and is now "morning planet," but is not yet in favorable position for observation.

Saturn will be visible during the first half of the night. During this month Saturn will make the turn of the loop in his apparent path through the constellation Virgo (see chart, p. 80), and will therefore appear to be nearly stationary among the stars. The planet will be recognized by its bright yellow color. The star just to the east of Saturn is the double star γ Virginis, a fine object for small telescopes. The Moon will pass by Saturn about a degree to the south on June 21, conjunction occurring at $10^h\ 16^m$ A. M. Saturn will be at quadrature, or just 90° east from the Sun, on June 27. The elevation of the Earth above the plane of the rings is now at about its minimum for this year, and during the remaining months the rings will gradually widen out so that more of their details may be seen. On June 9 the apparent major axis of the outer ring will be $40''.5$, and the minor axis $4''.3$.

Uranus will be found, about on the line between the constellations Virgo and Libra, a little over a degree east of the fifth-magnitude star λ Virginis. It is not visible to the naked eye, but may be easily recognized by its dull green disk with a telescope of moderate power. The Moon will pass Uranus, 1° 40′ to the north, June 23 at $10^h, 22^m$ central time.

Neptune will be behind the Sun on the morning of June 1, and will not be in position for observation for several months.

MERCURY.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	4 58.5	+ 23 33	4 20 A. M.	12 00.9 P. M.	7 42 P. M.
15......	6 32.0	+ 25 09	5 02 "	12 54.8 "	8 47 "
25......	7 50.8	+ 22 48	5 54 "	1 34.1 "	9 14 "

VENUS.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	5 35.8	+ 23 52	4 52 A. M.	12 38.2 P. M.	8 24 P. M.
15......	6 29.6	+ 24 10	5 05 "	12 52.5 "	8 40 "
25......	7 23.1	+ 23 17	5 24 "	1 06.6 "	8 49 "

MARS.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	7 17.5	+ 23 28	6 22 A. M.	2 05.8 P. M.	9 50 P. M.
15......	7 31.2	+ 23 00	6 13 "	1 53.9 "	9 35 "
25......	7 58.2	+ 21 54	6 06 "	1 41.6 "	9 17 "

JUPITER.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	2 58.2	+ 15 57	2 54 A. M.	10 01.9 A. M.	5 10 P. M.
15......	3 07.0	+ 16 34	2 21 "	9 31.2 "	4 42 "
25......	3 15.4	+ 17 07	1 48 "	9 00.4 "	4 13 "

SATURN.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	12 26.1	− 0 03	1 25 P. M.	7 27.3 P. M.	1 30 A. M.
15......	12 26.3	− 0 06	12 46 "	6 48.1 "	12 50 "
25......	12 27.0	− 0 14	12 08 "	6 09.5 "	12 11 "

URANUS.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	14 20.2	− 13 30	4 13 P. M.	9 21.1 P. M.	2 29 A. M.
15......	14 19.1	− 13 25	3 32 "	8 40.7 "	1 49 "
25......	14 18.4	− 13 22	2 52 "	8 00.6 "	1 09 "

NEPTUNE.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	4 39.2	+20 39	4 12 A. M.	11 41.8 A. M.	7 11 P. M.
15......	4 40.8	+20 42	3 84 "	11 04.1 "	6 34 "
25......	4 42.3	+20 45	2 56 "	10 26.3 "	5 56 "

THE SUN.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
June 5......	4 55.9	+22 38	4 18 A. M.	11 58.3 A. M.	7 39 P. M.
15......	5 37.3	+23 21	4 16 "	12 00.3 P. M.	7 45 "
25......	6 18.9	+23 23	4 18 "	12 02.5 "	7 47 "

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A................$0^h\ 52^m\ 32^s$
Decl.................+81° 17′
Period............2*d* $11^h 50^m$
1893.

June 2	3 A. M.
7	3 A. M.
12	3 A. M.
17	2 A. M.
22	2 A. M.
26	1 A. M.

S. CANCRI.

R. A................$8^h\ 37^m\ 39^s$
Decl................+ 19° 26′
Period............9*d* $11^h 38^m$

June 13	Midn.

δ LIBRÆ.

R. A..............$14^h\ 55^m\ 06^s$
Decl..............— 8° 05′
Period.........2*d* $7^h\ 51^m$

June 1	10 P. M.
8	10 "

δ LYRÆ CONT.

June 15	9 P. M.
18	5 A. M.
22	9 P. M.
25	5 A. M.
29	8 P. M.

U CORONÆ.

R. A..............$15^h\ 13^m\ 43^s$
Decl...............+ 32° 03′
Period...........2*d* $10^h\ 51^m$

June 18	4 A. M.
25	1 "

U OPHIUCHI.

R. A..............$17^h\ 10^m\ 56^s$
Decl...............+ 1° 20′
Period.......... 0*d* $20^h\ 8^m$

June 4	3 A. M.
4	midn.
5	8 P. M.
9	4 A. M.
9	midn.

U OPHIUCHI CONT.

June 10	8 P. M.
14	5 A. M.
15	1 "
15	9 P. M.
20	2 A. M.
20	10 P. M.
25	3 A. M.
25	11 P. M.
26	7 "
30	3 A. M.

γ CYGNI

R. A..............$20^h\ 47^m\ 40^s$
Decl................+ 34° 15′
Period............1*d* $11^h\ 57^m$

June 13	5 A. M.
16	5 "
19	5 "
22	5 "
25	5 "
28	5 "

Configuration of Jupiter's Satellites at 8^h p. m. Central Time.

June		June		June	
1	4 1 ○ 2 3	11	♃ 3 ○ 2 4	21	4 ○ 2 1 3
2	4 2 3 ○ 1	12	4 3 ○ 1 4	22	4 1 ○ 2 3
3	4 3 2 ○ ●	13	2 1 ○ 3 4	23	♃ 4 2 ○ 1
4	4 3 1 ○ 2	14	○ 2 1 3 4	24	4 3 2 1 ○
5	4 2 ○ 1 ●	15	1 ○ 2 3 4	25	3 4 ○ 1 2
6	4 2 1 ○ 3	16	2 3 ○ 1 4	26	3 ○ 4 2 ●
7	4 ○ 2 1 3	17	3 2 1 ○ 4	27	2 1 ○ 3 4
8	4 1 ○ 2 3	18	3 4 ○ 1 2	28	○ 1 3 4●
9	2 3 ○ 1 ●	19	4 3 ○ 2 1	29	1 ○ 2 3 4
10	3 2 1 ○ 4	20	4 2 1 ○ 3	30	2 ○ 3 1 4

Phases and Aspects of the Moon.

		d	h m	
Last Quarter..	June	7	7 43	A. M.
Perigee..	"	13	10 18	"
New Moon...	"	13	11 51	P. M.
First Quarter..	"	20	8 37	"
Apogee..	"	26	7 42	A. M.
Full Moon...	"	29	12 25	"

Mr. Marth's Ephemerides of the Satellites of Saturn.

[From *Monthly Notices*, March 1892.].

In this table the times have been changed from Greenwich Mean Time to Central Standard Time. The abreviations *Rh.*, *Te.*, *Di.*, *En.*, and *Mi.*, stand for the names of the satellites Rhea, Tethys, Dione, Enceladus. and Mimas The letters *a*, *b*, *c*, *d*, and *e*, stand for conjunctions of the satellites in order as follows: With the preceding end of the outer ring; with preceding end of planet's equatorial diameter; with center of planet; with following end of planet's diameter; with following end of ring. The letters *n* and *s* signify that the satellite at the time of conjunction is north or south of the point designated by the preceding letter; *Sh.* means that the shadow of a satellite is near the central meridian of the planet; *Ecl. D.* and *Ecl. R.*, the disappearance and reappearance of a satellite at beginning and end of an eclipse. The letters e and w standing alone signify eastern and western elongations.

May 1893.		
15	2.1 am	Ti an
	7.0 pm	Rh an
	8.8	Mi es
	9.5	Rh bn
	10.4	En as
	11.5	Rh cs
16	12.8 am	Te es
	6.1 pm	Di bn
	7.5	Mi es
	9.4	Di dn
	11.4	Te an
	11.6	Di en
17	6.1	Mi es
	10.1	Te es
	11.7	En en
	midn.	Mi as
18	12.1 am	Ti ds
	12.7	Di es
	1.2	Rh es
	8.7 pm	Te an
	9.0	Di w
	10.6	Mi as
	10.7	Te bn
19	6.7	En es
	7.4	Te es
	9.2	Mi as
	9.4	Te ds
20	12.3 am	Te bs
	6.0 pm	Te an
	6.4	Di es
	7.8	Mi as
	8.0	Te bn
	8.6	Di ds
	10.9	Te dn
	11.9	Di bs
21	6.4	Mi as
	6.7	Te ds
	8.0	En an

May 1893.		
21	11.6 pm	Te bs
22	6.1	Rh inf
	6.8	En as
	8.0	Rh bs
	8 2	Te dn
	10.2	Te en
	10.5	Mi an
	10.6	Rh as
	11 5	Di en
23	7.8	Di as
	8.9	Te bs
	9.1	Mi an
	9.2	Rh w
	9.4	En es
	10.9	Te as
24	7.5	Te en
	7.7	Mi an
	7.8	Rh an
	8.2	En en
	8.9	Di an
24	10.8	Rh bn
	11.1	Di bn
25	12.8 am	Rh sup
	6 2 pm	Te as
	6.3	Mi an
	10.7	En an
26	9.5	En as
27	8.1	Di dn
	9.5	Mi en
	10.8	Di en
28	8.1	Mi en
	10.8	En en
	11.4	Di es
29	6.7	Mi en
	7.7	Di w
30	10.7	Mi es
31	12.1 am	En as
	6.9 pm	Rh inf

May 1893.		
31	7.3 pm	Di ds
	8.8	Rh bs
	9.3	Mi es
	10.6	Di bs
	11.4	Rh as
June		
1	12.8 am	Di as
	7.1 pm	En an
	8.0	Mi es
	10.0	Rh w
2	12.5 am	Te es
	6.6 pm	Mi es
	8.6	Rh an
	10.2	Di e
	11.1	Rh bn
	11.2	Te an
3	6.5	Di as
	8.5	En es
	9.8	Te es
	11.1	Mi as
	11.8	Te ds
4	7.2	En en
	7.7	Di an
	8.5	Te an
	9.7	Mi as
	9.9	Di bn
	10.5	Te bn
5	6.1	Te es
	8.3	Mi as
	9.1	Te ds
	9.8	En an
6	7.0	Mi as
	7.8	Te bn
	8 6	En as
	10.7	Te dn
7	6.0	Rh en
	6.4	Te ds
	6.8	Di dn

June 1893.		
7	9.1 pm	Di en
	9.3	Te bs
	11.0	Mi an
	11.1	En es
	11.3	Te as
8	8.0	Te dn
	9.6	Mi an
	9.9	En en
	10.0	Te en
	10.2	Di es
9	6.5	Di w
	6.7	Te bs
	7.7	Rh inf
	8.2	Mi an
	8.7	Te as
	9.6	Rh bs
10	12.2 am	Rh as
	6.8 pm	Mi an
	7.8	Te en
	10.8	Rh w
11	6.0	Tr as
	6.1	Di ds
	9.4	Di ds
	9.4	Rh an
	11.4	Mi en
	11.6	Di as
	midn.	Rh bn
12	6.2 pm	En an
	10.0	Mi en
13	8.6	Mi en
	9.0	Di e
14	7.2	Mi en
	7.6	En es
15	6.4	En en
	6.4	Di an
	8.6	Di bn

Phenomena of Jupiter's Satellites.

1893.		h	m						h	m			
June	3	3	15	A. M.	I	Sh. In.	June	19	2	21	A. M.	I	Tr. In.
	4	3	19	"	I	Oc. Re.		20	1	49	"	I	Oc. Re.
	11	2	25	"	I	Ec. Dis.		20	3	02	"	II	Tr. In.
	12	2	36	"	I	Tr. Eg.		24	2	38	"	III	Tr. Eg.
	13	2	37	"	II	Tr. Eg.	July	1	2	54	"	III	Sh. Eg.
	13	3	03	"	III	Ec. Dis							

Occultations Visible at Washington.

				IMMERSION			EMERSION			
Date 1893.		Star's Name.	Magnitude.	Washington M. T.		Angle f'm N pt.	Washington M. T.		Angle f'm N pt.	Duration.	
				h	m	°	h	m	°	h	m
June	4	38 Capricorni	6.9	13	29	40	14	43	276	1	14
	22	*h* Virginis	5.8	7	01	138	8	27	303	1	26

New Minor Planets.—These are being discovered at such a rate that several alphabets are likely to be exhausted during this year if we continue to designate them by the present method:

	Mag.	Discoverer	Gr. M. T.		R. A.	Decl.	Daily Motion. R. A.	Daily Motion. Decl.
				h m	h m s	° ′	s	′
1893 K	12.5	Charlois	Mar. 8	9 16	10 53 36	+ 6 13	−48	+7
L	9	"	9	8 34	10 08 48	− 0 43	−56	+3
M	13	"	10	10 57	11 41 28	+ 4 35	−52	+5
N	12	"	11	9 56	11 28 36	+14 06	−48	+7
O	12	"	11	9 56	11 31 56	+15 43	−52	+7
P	13	"	11	12 56	11 36 52	+11 49	−52	+3
Q	12	Wolf	16	12 00	11 11 24	+ 8 52	−40	+7
R	11	Charlois	17	10 52	12 19 16	+ 4 38	−56	+4
S	12	"	17	12 01	10 50 16	+16 50	−44	+2
T	12	"	19	10 26	11 52 52	+11 29	−52	+5
U	13	"	19	10 26	12 01 12	+14 20	−56	+8
V	13	"	21	10 11	12 08 52	− 2 09	−52	+6
W	12	"	21	10 11	12 20 36	− 7 25	−52	+2
X	12.5	Wolf	21	11 25	12 25 52	− 0 43	−40	+5

From the *Astronomical Journal*, No. 294, we learn that the asteroids of 1892 from O onward have received numbers as follows:

1892 O (Charlois Nov. 23) = No. 345
P (" " 25) = " 346
Q (" " 28) = " 347
R (" " 28) = " 348
S (" Dec. 8) not numbered.
T (" " 9) = No. 349
U (" " 14) = " 350
V (" " 16) = " 351

Mr. Charlois has assigned names, as below, to four of those discovered by him:

314 1891 Sept. 1, Rosalia.
316 1891 Sept. 8, Goberta.
317 1891 Sept. 11, Roxana.
349 1892 Dec. 9, Dembowski.

COMET NOTES.

No comets have been discovered so far this year, nor has the periodic comet of Finlay been yet picked up. We continue the search ephemeris for the latter below.

Ephemeris of Comet Finlay (1886 VII).

(From *Astr. Nachr.* 3154.)

Paris M. T.	App. R. A.	App. Decl.	log. Δ	$1 : r^2\Delta^2$
	h m s	° ′		
1893 May 16	23 31 25	− 6 09.6	0.1178	0.355
17	35 35	5 43.6		
18	39 46	5 17.3		
19	43 58	4 50.7		
20	48 12	4 23.9	0.1070	0.394
21	52 28	3 56.8		
22	23 56 45	3 39.4		
23	0 01 04	3 01.8		
24	05 24	2 33.9	0.0973	0.434
25	09 45	2 05.8		
26	14 08	1 37.5		
27	18 32	1 09.0		
28	22 57	0 40.4	0.0890	0.475
29	27 24	− 0 11.6		
30	31 52	+ 0 17.3		
31	36 22	1 46.4		
June 1	0 40 53	+ 1 15.6	0.0821	0.515

Our last sight of Holmes comet was had on the night of April 3, when the comet with the 16 inch telescope was exceedingly faint. It was perhaps 2′ in diameter with a very slight central condensation. It was impossible to obtain a micrometrical measure of the comet's position.

Mr. C. C. Hutchins sends us a sketch of Holmes' comet made with a 12-inch reflector, power 85, on the night of Nov. 20, which agrees closely with our own sketches about that time. He calls attention to the fact that the appearance of the comet was quite different from that indicated by the sketches of Mr. Denning, reproduced in the frontispiece of our last number. The tail of the comet, instead of narrowing and producing the pear-shape indicated by Mr. Denning, gradually widened, giving the usual paraboloidal form. The granular structure of the little bright tail back of the nucleus was not noticed, nor was there any dark space around it.

Elements of Comet 1893 I (Brooks *g*, 1892).—The following are the elements of Comet 1892 *g* as computed by Mr. Isham and myself from all observations available up to the present time:

$$\begin{aligned} T &= 1893,\ \text{Jan. } 6.53308 \text{ Berlin M. T.}\\ \Omega &= 185^\circ\ 39'\ 17''.8\\ i &= 143\ \ 51\ \ 48\ .4\\ \omega &= \ \ 85\ \ 13\ \ 18\ .5\end{aligned}\left.\vphantom{\begin{aligned}\Omega\\ i\\ \omega\end{aligned}}\right\}1893.0$$

$$\log q = 0.0774075$$

and the equatorial co-ordinates for 1893

$$\begin{aligned} x &= [9.9992656]\, r \sin\,(350^\circ\ 38'\ 58''.5 + v)\\ y &= [9.7081212]\, r \sin\,(\ \ 75\ \ 01\ \ 31\ .3 + v)\\ z &= [9.9353820]\, r \sin\,(\ \ 82\ \ 36\ \ 48\ .3 + v)\end{aligned}$$

We did not think it worth while to prepare any ephemeris as it is scarcely possible that the comet will be visible.

J. G. PORTER.

NEWS AND NOTES.

Inadvertantly we have sent a few numbers of this publication to some subscribers who have not renewed for this year, or ordered discontinuance. We are sorry to drop any names in this way, but we are obliged to do it, in view of the heavy expense incurred in publishing so much as we do each month. We must know what our support is to be for the year and plan accordingly. Notices are sent once more and the journal will be withheld until orders are received.

Popular Astronomy.—A great many letters have been received from different parts of the United States, Canada and Europe, in relation to suggestions in the April number of ASTRONOMY AND ASTRO-PHYSICS about a new publication devoted to "*Popular Astronomy*" to meet the wants of students, teachers, popular readers and amateurs. The interest manifested so far seems unexpectedly great. We now respectfully ask *every reader of this paragraph*, as a contribution to this worthy undertaking, that you send one or more names of those likely to be interested in such a monthly periodical to the publisher of this journal for the purpose of further correspondence. If such a publication is really needed, and there is sufficient support promised to make the undertaking successful financially, and useful in a high degree, it will be promptly undertaken. Otherwise it will not be tried. *Send us names.*

Screens to Protect Telescopes from Wind Tremors.—*To the Editor of Astronomy and Astro-Physics:* I have, naturally been quite interested in the discussion which has sprung up as to how to protect the great telescope at Mt. Hamilton from wind tremors, and venture to make a modest contribution to the subject in hand Some three years ago Mr. S. W. Burnham, then astronomer here, complained of such tremors, and I had a machinist put up two rods inside the dome, one on each side of the slit, and fit a series of loose sliding rings to each rod. We never went so far as to attach canvas to these rings, for Mr. Burnham finally decided that he did not wish it to be done on his account.

These rods and rings have been in place for several years, and any of the expedients suggested can be tried at any time in half an hour by anyone interested who knows of the existence of the rods, etc.

Professor Winnecke once advised me to have the slit of the great dome extended from horizon to horizon. I decided for a 90° (or so) slit, and the suggestions which we have heard prove that this decision was a correct one.

I am, dear sir, very respectfully,

Lick Observatory, 1893, April 20. EDWARD S. HOLDEN.

Missouri Botanical Garden—Banquet of the Trustees.—The Fourth Annual Banquet of the Trustees of the Missouri Botanical Garden will be held May 17, 1893. We notice the name of Professor Henry S. Pritchett, Director of the Observatory of Washington University, in the list of trustees. The following gentlemen have promised to be present and speak at the trustees' banquet:

President Wm. R. Harper, of the University of Chicago.
President R. H. Jesse, of the University of the State of Missouri.
President C. K. Adams, of the University of Wisconsin.
Professor T. C. Mendenhall, Superintendent of the U. S. Coast Survey.
Professor T. C. Chamberlin, of the University of Chicago.
Professor Geo. L. Goodale, of Harvard University.
Professor Asaph Hall, of Washington.
Professor C. O. Whitman, of the University of Chicago, and
His Excellency, Governor Wm. J. Stone.

The Large Nebula near ξ Persei (N. G. C. 1499).—In *Astronomische Nachrichten* No. 3157, Dr. F. Scheiner gives a drawing of this nebula from photographs of from 1 to 6 hours exposure. He used a Voightlander Euryscope lens of 4 inches aperture and focal distance 3⅛ to 1. He finds that with the 6-hour exposure the nebula is much more extensive than it has ever before been known to be, and approaches nearly the size of the Andromeda and Orion nebulæ. This nebula was discovered by Barnard with a 6-inch photographic lens. It extends, in Scheiner's drawing, from R. A. 3^h 56^m Decl. + 35° 15′ to R. A. 3^h 45^m Decl. 36° 40′ and is from 30′ to 50′ in width. There are suggestions of spiral curves but none so definite as those of the Andromeda nebula.

Astronomical Observations at the Royal Observatory of Prague for the years 1888, 1889, 1890 and 1891.—We have been favored with a copy of the Astronomical Observations made at the Royal Observatory of Prague during the years 1888 to 1891, by the director of the Observatory, Professor L. Weinek. It is a neat large quarto volume of 90 pages giving observations of moon culminations for the year 1888, observations of latitude by the Horrebow-Talcott method from 1889 to 1892, observations of comets Sawerthal 1888 I, Barnard 1889 I, and other phenomena of interest during the time above mentioned. A very interesting part of the volume is devoted to special work in study of particular objects on the surface of the Moon. Some fifty pages of the text are given to the description of prominent objects chosen with full study of details. These subjects are illustrated by drawings and most beautifully executed plates by the heliographic process. The reproduction of one of the Moon's photographs taken at Lick Observatory by the aid of the 36-inch equatorial is an exquisite piece of work. The full page illustration of Professor Weinek's Meridian Circle room gives a good idea of his interesting work-shop.

Distances of the Stars by the Doppler's Principle.—An interesting paper appeared in the April number of the *American Journal of Science* in relation to stellar distances by the Doppler's principle. The author is Mr. G. W. Colles, Jr., and a brief review of his paper follows.

The first mention of the application of the Doppler's principle for finding stellar distances was by Fox Talbot in a paper read before the British Association in 1871, in which he showed how the principle might be applied in determining the distances of binary systems. His plan was to measure the relative velocities of each of the components of the binary when they were moving in the line of sight by the aid of the spectroscope. The shape of the orbit being known, the proportionate velocities of the stars at any point in it are known. Now since the *absolute* velocities at one point in the orbit are known, they can be deduced for a point where the stars are moving across the line of sight. Then find the angular velocity at this point, and divide the computed linear velocities by it, and the result will be the distance of the system.

In 1886 Professor A. A. Rambaut, Astronomer Royal of Ireland fully discussed Talbot's plan in papers published in the Proceedings of the Royal Irish Academy, and in the *Monthly Notices*, under the title of "On the Parallax of Double Stars." This principle could be extended to multiple systems, but for the lack of knowledge of the inclination of the plane of revolution in the line of sight. It can not be applied to find the distance of any single star, because the exact direction of that star's motion is not known. If any star should move rapidly enough, or instrumental measures should ever become accurate enough, so that an observer could detect the increase or decrease of its annual angular motion its distance might be determined approximately.

The author's purpose in this paper, however, is to suggest a much wider application of the Doppler's principle than those indicated above. It is to undertake the problem of the mean distance of all the stars, involving the theory of probability, in the hope, thereby, of gaining a more or less reliable idea of the extent of the cosmos.

His solution of this problem proceeds in this way: Suppose a *very* large number of stars to be distributed equally over the celestial sphere, with motions perfectly at random and represented by straight lines, and that the velocity in the line of sight and the proper angular motion of each star are accurately known, then the ratio of the mean velocity of the star across the line of sight to its mean velocity in the line of sight may be obtained. The analysis by which the mean distances of the stars are made a simple function of the mean angular velocity and mean velocity in the line of sight is worthy of a full statement which lack of space forbids. We can only say that the application of the formula derived gives as a mean distance of the brighter stars used, a distance of 9,596,000 astronomical units which equal 150.9 light-years. If the velocites of stars in the line of sight as measured by Vogel are used, the result is less, 5,115,000 astronomical units or 80.5 light-years. Though at present this problem is beset by some difficulties almost insuperable, it will in time, offer advantages for determining stellar distances in a way not now even attempted.

The Mechanics of the Earth's Atmosphere.—Professor Cleveland Abbe has done excellent service to science in providing translations of some of the most important recent papers treating of the mechanics of the atmosphere. A pamphlet consisting of 324 pages, prepared by Professor Abbe for the Smithsonian miscellaneous collections contains:

1\. *Hagen*, 1874. The measurements of the resistences experienced by plane plates when they are moved through the air in a direction normal to their planes.

2\. *Helmholtz*, 1858. On the integrals of the hydrodynamic equations that represent vortex motions.

3\. *Helmholtz*, 1868. On discontinuous motions in liquids.

4\. *Helmholtz*, 1873. On a theorem relative to the movements that are geometrically similar, together with an application to the problem of steering balloons.

5\. *Helmholtz*, 1888. On atmospheric motions, two papers, and a third on the theory of wind and waves.

7\. *Helmholtz*, 1890. The energy of the billows and the wind.

8-13. *Overbeck*, 1882-1888. Four papers.

Then follow other papers by Hertz, Benzol, Rayleigh, Margules and Ferrel.

Catalogue of 3415 Southern Stars.—The American Academy of Arts and Sciences has recently published No. 1 of Vol. XII of its Memoirs, which is a catalogue of the magnitudes of southern stars from 0° to — 30° declination to the magnitude 7.0 inclusive. This work was done by Edwin F. Sawyer, well known observer of variable stars. It was begun in 1882, nearly finished in 1887, and completed in 1890. The whole number of observations is 13,654 on 3,415 stars, the average of observations to each star being 4. This catalogue may be regarded as an independent revision of Dr. B. A. Gould's *Uranometria Argentina*. The method of observation was by step-estimations, and each sequence comprised about ten stars, if enough desirable stars for comparison were near, if not, five or six; in some cases, twenty were used. The brightest in the region was first selected, then the next brighter, and so on down, other stars afterwards being inserted in their appropriate places. The various differences of brightness were estimated in steps. When all the stars in a given neighborhood had been so observed, a new sequence was begun and so on.

Nearly half of the whole work was done during the first year of observation, and the opera glass only was used. Afterward for the fainter sequences a field glass was employed. This would be necessary in observing sixth magnitudes and fainter ones. When a sequence was undertaken with any particular instrument that sequence would be completed with the same instrument. The observations were made with the instrument a little out of focus, so as to expand the light of the stars into a disc and comparisons were then made. This method was thought to be the most trustworthy, especially in the case of the colored stars. The observations were generally made during nights free from clouds and moonlight, and usually between the hours of 6 and 12 mean time.

The reductions of the sequences was done graphically on squared paper, the *Uranometria Argentina* magnitudes being used as ordinates and the observed differences of brightness expressed in steps as abscissas.

The care with which this piece of work seems to have been done and the ability of the observer put into it makes it a valuable catalogue. It will show amateurs what can be done with the opera glass and some patient practice in observing.

Paris Observatory in 1892.—From the annual report of the Director of the Paris Observatory for 1892 we take the following notes concerning the work of the Observatory during that year:

In the beginning of his first report the director, M. Tisserand, refers to the great loss which the institution sustained in the death of Admiral Mouchez and to the great work which the latter had initiated and in part successfully carried out, and announces his own determination so far as possible to carry these on to successful completion. At the suggestion of M. O. Struve, the presidency of the Permanent Committee on the Photographic Chart of the Sky has passed to the present director of the Paris Observatory. He has begun his endeavors to advance the project by increasing the personnel of the bureau for the measurements of the photographic plates at the Observatory and by having a new machine constructed for these measures.

The meridian circle work has been carried as heretofore, eleven observers taking part, and making a total of 16,686 observations. The great reflector has been devoted to spectroscopy, in charge of M. Deslandres, who has already determined the velocities in the line of sight of a number of stars. It is intended to determine the velocities of about 250 stars in this way. M. Deslandres has also succeeded in photographing solar prominences and faculæ and some new hydrogen lines.

The great Equatorial Coudé has been modified somewhat and is now ready for regular work. Other instruments have been used as heretofore in determining the places of comets and asteroids and in miscellaneous observations.

In the report of the bureau of measurements of the plates for the catalogue, are some interesting remarks on the magnitude of this work. Supposing each plate to contain 200 stars it requires 16 or 17 hours to measure one plate. Two persons with one machine could measure 130 plates per year. As each of the 18 observatories engaged in the work is expected to obtain from 1200 to 1400 plates, it would take the two persons ten years to measure the plates from one Observatory or 180 years to measure them all. Then the reductions of the measures would require further labor. To publish the catalogue would require 40 volumes of 1000 pages each with 50 stars to a page. And yet, some very eminent astronomers think that this ought to be done.

The Asteroid Collision Hypothesis—Answer to Mr. Holmes' Objections. The communication of Mr. Edwin Holmes to the "Comet Notes" of No. 114 of A and A.-P. contains the statement of certain objections which he urges against the validity of the "asteroid collision" hypothesis of the origin of the celestial body which bears his name, that seem to require a reply from me. Considering these objections in the order of their importance, as I conceive it, the first is "that the mutual perturbations of the two asteroids in hypothetical collision, would operate to prevent such a catastrophe by shifting the bodies under consideration, so that they would pass by each other instead of colliding and that they would then form a "binary system" or a double asteroid. My answer to this is that the mutual perturbative action aforesaid might or might *not*, cause the effects stated. The question whether it would or would *not*, depends upon the masses of the asteroids, the elements of their orbits, and the directions of their motions, and it is *possible* for these to have such values as to render the perturbation of the radius-vector extremely small, or even practically nothing. While it is true that two asteroids moving so that they would collide if undisturbed, can by perturbation be turned aside and pass each other, it is equally true that two such bodies, moving so that they would pass each other if there were no mutual perturbing force, could be brought into collision by their mutual attraction. Furthermore, in considering the motion of any celestial body, only that of a *material point*, that is the "centre of gravity" of the body, is regarded. Now, while it goes without saying that the collision of *material points* would be practically impossible, it should be noted that the asteroids, comparatively small though they be, are very far from being material points; their volumes are such that while it might be impossible for them to so collide that the impact would be "central," there is no reason why an "eccentric" impact could not occur. Moreover the masses of these bodies are so small that either of the two asteroids cannot materially change the velocity of the other unless they are very nearly in actual contact. As I have shown in No. 114 of A. AND A.-P., the velocity generated by the mass of an asteroid 74 miles in diameter (and this is a maximum value in the present case) would be only about 341 feet per second, at the very surface of such body. Now, unless the relative velocity of any two such asteroids were less than this, they could not form a "binary system" or a double asteroid; they would separate and move on around the Sun in slightly altered orbits. A relative velocity so small as 341 feet per second, is extremely improbable as between two asteroids; but admitting the existence of a "binary system" composed of two such bodies revolving freely around a common "centre of gravity," the perturbative action of the other bodies of the "solar system," particularly the larger ones, could so operate as to produce an "eccentric" impact between these asteroids, a possibility which suggested to me, when I first considered this subject, the hypothesis of a collision between the members of such a "binary system," but this hypothesis I rejected for certain good reasons, in favor of that of a direct collision. In view of the facts above set forth, I think that, in the face of the circumstantial evidence, that has been produced, the weight of the objection stated above, is practically nil.

Another objection advanced by Mr. Holmes, is that such a collision should generate heat sufficient to render the matter self-luminous, or to reduce it to fluidity or even to the vaporous state in which there could be no nucleus, and that the spectroscope shows no such condition. This objection is quite fully answered in my communication to No. 114 of A. and A.-P., in which I have shown that the circumstances of the collision were such as to render the generation of a quantity of heat sufficient to produce the above described effects, or to give a characteristic spectrum, very improbable or even impossible. My investigation on this point has shown, to a practical certainty, that the effects, in this respect, were solely mechanical, consisting of the complete, or partial rupture of one or of both of the colliding bodies and the dispersion of the resulting particles, the work performed in overcoming the force of "cohesion," and in imparting velocity to the particles (to say nothing of the cooling by "radiation") using up the greater portion of the kinetic energy that would otherwise have been converted into heat and, therefore, leaving the body to shine only by reflected light, as the spectroscope indicates that it did.

A third objection advanced by the discoverer is "that the nebulous envelope of the body maintained a circular form (as it appeared to us) for three days after the date of discovery" which fact Mr. Holmes thinks incompatible with the idea of a "collision," although he says that subsequent developments appear to favor the "collision hypothesis." In answer to this I would say that, according to that hypothesis the reasons why this nebulous envelope first appeared in circular form, are the following: Any asteroid can properly be regarded as a spherical body possessing some, and probably considerable, elasticity, and as one having on its surface more or less loosely associated and finely divided matter. To illustrate, we may regard each asteroid as a ball of iron, if indeed it be not, in reality, principally composed, like many meteoric bodies, of that metal or of similar substances. The first effect of the impact would be a concussion or an internal vibratory movement of the mass of the asteroid as a whole, and this would cause the projection of the loosely associated surface matter outward radially (this direction being in the line of least resistance) at a very high velocity owing to the very small masses of the surface particles, these being comparable to dust. Since the diameters of the two bodies in contact were so small that the contiguous bodies would form a mere point in comparison to the great diameter of the nebulous envelope, or to the distance to which the surface matter was projected, the latter must have practically assumed the form of a sphere and appeared to us as a circular nebulous disc. This action was the first to take place, and was entirely distinct from that which resulted subsequently in the elongation of the envelope, and the formation of the so called "tail," which were both mainly due to the movement of the particles resulting from the rupture, in their orbits around the Sun, resultants of the orbital motions of the original asteroids.

The futility of two of the three objections urged by Mr. Holmes against the asteroid collision hypothesis (the third having been already disposed of) can be even more forcibly demonstrated as follows: In the first place, in order that two asteroids each 60 miles in diameter, for instance, and moving so that they would collide centrally were there no mutual perturbative action between them, should by such action be caused to pass by each other, it is, evidently necessary that the center of gravity of each asteroid should by perturbation, be shifted 30 *miles*, the displacements being in opposite directions. Now, I have computed the maximum effect of this perturbative action upon each radius-vector in the case of two such asteroids having the masses given in No. 113 of A. and A.-P., and under the conditions existing in the present case, and I have found that such an effect would not exceed 66 *feet* in each case. Therefore the contention that mutual perturbation would prevent the collision of two such asteroids is futile.

Secondly, the reason for the *circular* form of the nebulous envelope during the first three days after discovery, can be illustrated as follows: An asteroid can, of course, be regarded as a body expansible by heat. We may also consider it as a sphere of iron 60 miles in diameter. Such a body out in the cold of space could be heated through about 1500° Fahr. before becoming self-luminous; that increase of temperature would cause expansion, the co-efficient of which, in the case of iron, would indicate an augmentation of about 1600 feet in the radius of the sphere. Therefore, if the increase of temperature and the consequent expansion took place in one second, loose matter on the surface of the sphere would be projected upward radially with a uniform velocity of 1600 feet per second, as by a shock or concussion, while an equal expansion in a shorter time would generate a greater velocity.

The loss of kinetic energy due to the impact, and the consequent heating and expansion of the colliding bodies must have occurred in a very brief interval, or almost instantaneously, and since it would require a velocity of only about 341 feet per second to project matter from the surface of such bodies so that it would never return, it is plain that the first effect of a collision would be to project loose surface matter radially outward at high and uniform velocity, and thus to form the spherical envelope which appeared to us as the *circular* nebulous disc.

Since all of Mr. Holmes' objections have thus been, I think, satisfactorily refuted, it follows that his conclusions that the "asteroid collision" hypothesis must be rejected," is unwarranted. On the contrary, since all the observed phenomena in this case are explicable by that hypothesis, and by none other that I know of, while the body discovered by Mr. Holmes has not exhibited any of the significant characteristics of a comet. I think that this "hypothesis" should be accepted if the recognized "criteria" determining the question of acceptance or of rejection, of any hypothesis, is not to be arbitrarily set aside in a most unscientific manner. In conclusion I would say that while I have, from the first recognized the great improbability of a collision between two asteroids considered as an abstract proposition, I have also been cognizant of the fact that even a *great improbability* is very far from being equivalent to an *absolute impossibility*. The matter is simply reduced to a question of evidence, and this I have endeavored to furnish in the two immediately preceding numbers of "ASTRONOMY AND ASTRO-PHYSICS." A collision at some definite point upon any ocean, between two vessels departing from widely separated ports and destined for points equally far apart, is a *very great improbability*, yet we know that such catastrophes have occurred, and not infrequently, and when we have the evidence of the wreckage even the *great improbability* counts for nothing.

Now, in the case under discussion, it is quite evident that astronomers have had before their eyes for several months past the *wreckage* resulting from the *collision* of two asteroids and which has been known as Holmes' comet.

SEVERINUS J. CORRIGAN.

ST. PAUL, Minnesota, April 8th, 1893.

Chicago Academy of Sciences.—Section of Mathematics and Astronomy.—The regular meeting of the Section was held at the Chicago Athenæum on Tuesday evening, March 7, 1893. Professor G. W. Hough presided.

Mr. A. C. Behr read a translation of Dr. Seeliger's paper on "General Problems in Celestial Mechanics. In the discussion Messrs. Burnham, Hough, Crew, See, Pike and Hale took part.

The second paper, on "Variations in the Calcium Spectrum from the Bunsen Flame to Sirius," was presented by Messrs. G. E. Hale and S. B. Barrett, and discussed by various members present. An abstract of this paper will be found on another page.

Adjourned. GEORGE E. HALE, Recorder.

The regular meeting of the Section was held at the Kenwood Observatory on Tuesday evening, April 4, 1893, Mr. R. W. Pike in the chair.

Professor G. E. Hale read a paper on "Present Limitations of Astronomical Photography," in which the difficulties due to coarseness of silver grain, lack of orthochromatism (a disadvantage only in the case of spectroscopic work, and in photography with a reflector), halation and enlargement of the image with prolonged exposure, and the impossibility of giving a correct exposure for objects of different degrees of brightness in the same field of view, were discussed and illustrated by lantern projections. It was shown that while in many directions photography has far surpassed visual observations, yet in others—such as the study of the Moon and planets, the minute details of Sun-spots, and the discovery and measurement of double-stars—it is still of little or no practical value.

In his remarks on the paper Mr. Burnham discussed Herr Weinek's alleged discovery of lunar rills, and showed that no amount of enlargement could bring out more detail on a photograph than is contained in the original—a point by no means generally understood. Referring to Dr. Robert's recent note on the absence of any indications of nebulosity in his photographs of Nova Aurigæ he remarked that the extremely faint nebulosity would require so prolonged an exposure that the image of the star would be greatly over-exposed, and the nebulosity would of necessity be completely hidden from view on the photographs.

Professor Hough discussed the sensitiveness of photographic plates and the employment of collodion plates in astronomical photography.

It was unanimously agreed that while it is not desirable to very greatly increase the sensitiveness of plates for most branches of astronomical photography, on account of the extreme difficulty of guarding against fog, every effort should be made to decrease the size of the silver grain, at the same time retaining at least the present degree of sensitiveness.

Adjourned. GEORGE E. HALE, Recorder.

New York Academy of Sciences.—Section of Astronomy and Physics.—Minutes of the meeting, 1893, April 3. The Section was called to order at 8:15 P. M., Professor Rees in the chair. The minutes of the previous meeting having been approved, a paper was read by Professor William Hallock entitled "Investigations of the Temperature of the Earth's crust." This paper gave an account of temperature measures made at Wheeling, W. Va., in a dry well 4,500 feet deep. These measures, when plotted, showed a small but distinct variation from uniformity in the rate of increase of the Earth's temperature. The results have been described in *Pro. Am. Assn.*, Vol. XL, p. 257; and *Am. Journ. Sci.*, 1892, March.

Mr. Tatlock then read a note on the place of λ Ursæ Minoris, calling attention to the bearing upon the subject of Dr. Elkin's recent heliometric triangulation of close polar stars. The matter was further discussed by Professor Safford and Mr. Jacoby. Professor Safford read a paper entitled, "The construction of a catalogue of standard polar stars." This paper dealt with the various peculiar difficulties attending the observation of close polar stars, as well as the complexity and great length of the resulting computations. The author referred to his own work in this direction, and stated that he hoped to publish before long a complete discussion of all existing observations of close polars.

HAROLD JACOBY, Sec'y of the Section.

Astronomical Society of the Pacific.—Annual meeting of the Astronomical Society of the Pacific was held in the lecture hall of the California Academy of Sciences, March 25, 1893. Vice President Molera occupied the chair. The following papers were presented:

Physical Observations of Jupiter's Satellites in Transit by John Tebbutt, of New South Wales; Solar Motion, by W. H. S. Monck, of Dublin; A Summary History of Astronomy in America from 1620 to 1893, by Edward S. Holden; Evolution of Double-Star Systems by T. J. J. See, of Chicago; Surface Markings of Mars (with lantern slides) by W. J. Hussey, of the Stanford University. Two new Planispheres by W. J. Hussey; Miscellaneous Observations of Nova Aurigæ, W. W. Campbell, of Mt. Hamilton; An Easy Method of Adjusting an Equatorial Telescope, by Roger Sprague, of Napa, Cal.; Astronomical Observations for 1892, by T. Köhl, of Odder, Denmark.

The report of the committee on the comet medal related to the calendar year, 1892. The comets for that year were:

Comet *a*; (unexpected) discovered by Lewis Swift, of Rochester, N. Y., March 6.

Comet *b*; (Winnecke's periodic) re-discovered by R. Spitaler, of Vienna, March 18.

Comet *c*; (unexpected) discovered by W. F. Denning, Bristol, England, March 18.

Comet *d*; (unexpected) discovered by W. R. Brooks, Geneva, N. Y., August 28.

Comet *e*; (unexpected), discovered by photography by E. E. Barnard, of Lick Observatory, October 12.

Comet *f*; (unexpected), discovered by Edwin Holmes, London, Eng., Nov. 6.

Comet *g*; (unexpected), discovered by W. R. Brooks, Geneva, N. Y., Nov. 19.

The comet medal has been duly transmitted to the discoverers of comets *a*, *c*, *d*, *e*, *f*, *g*, in accordance with the regulations. A copy of the comet-medal has been presented to the Royal Society of London, in the name of the Astronomical Society of the Pacific, in accordance with a resolution of the board of directors adopted Nov. 26, 1892.

The photograph of a meteor trail by John E. Lewis, of Ansonia, Conn., was exhibited to the members of the society. Mr. Molera gave an address and at its conclusion presented the society with twelve beautiful photographs, showing the buildings and instruments of the National Observatory of Tacubaya, Mexico. W. J. Hussey delivered a lecture on the planet Mars, illustrated by over one hundred slides of the most important drawings made of the markings of the planet from the invention of the telescope to and including the last opposition. After other routine business the meeting adjourned.

The Astronomical and Physical Society of Toronto.—At the meeting of this society held March 21st, a long series of stellar planetary and solar observations was reported. The papers read included one by Mr. J. A. Copeland, on Holmes' Comet, and five upon Saturn. With a view to interesting members in that planet, a series of short papers was invited. More were offered than could be read. Those read included: "The Discovery of Saturn, his Rings and Moons," by Miss S. L. Taylor; "Saturn as a Habitable Globe," by Mr. G. G. Pleasey; "Phenomena Connected with the Disappearance of Saturn's Rings," by Dr. A. D. Watson; and "The Simple Mathematics of Saturn," by Mr. A. Harvey. The experiment was a success.

At the meeting of April 4th, a letter was read from Professor W. H. Pickering who expects to publish his report on Mars soon after his return to the United States which will take place in a few months, and who anticipates that the nomenclature of Mars will be one of the subjects dealt with by astronomers during the World's Fair. The paper of the evening was entitled "The Canals of Mars," and was contributed by Mr. S. E. Peal, F. R. A. S., of Sibsagar, Asam, India. Mr. Peal said that if the geological axiom of the permanent subsidence of ocean floors, so clearly seen on the Earth and Moon, applies to Mars, we can see at once that the completeness of the equatorial land girdle is due to the absence of tidal rupture by a large satellite and also an intelligible reason for the origin of the 'canals' as tideways open to the polar basins at each end, and that this peculiar arrangement was, there could scarcely be a doubt, due to the following causes: (a). That on Mars, the earlier phases of crust formation began at the poles, which, as time passed, became sea basins; that by the slow subsidence of the floors of these polar oceans, which would be the coldest and densest portions of the crust, the emergence of the equatorial land girdle would at last follow as a natural consequence; (b). That the comparative continuity of this latter would be assured by the absence of a large satellite causing tidal rupture, as in our case, the solar influence being, according to Professor Darwin, "inconsiderable." But though "inconsiderable," the solar influence would yet cause limited tides, a little before, during and after the equinoxes and tend to cause an "over-spill" from one basin into the other when one of the poles was turned toward the Sun. Such tide-water passing across the equatorial land girdle by the lowest levels would cause channels or "canals" which the "bore" would tend to straighten, especially if in alluvial strata. At the equinoxes the tides would, during the day time, be drawn up the canals from each polar basin on to the equatarial region by solar attraction, the return flow taking place at night. Thus, even with limited tides, the effectual circulation of water on Mars would probably much exceed that seen on our Earth and its heating by the solar rays to a large extent daily in the tropics would be greater than with us. The circulation of this heated water in each polar basin might well account for the smallness of the "polar caps," the net-work of canals across the equator acting as an efficient water heater, mitigating thereby the rigors of the arctic and antarctic climates. The occasional duplicity of the canals may possibly be due to the presence in them of a series of islands, like the sand "churs" of our Brahmapootra, a river which is very seldom, indeed, found to flow in one channel, and some of whose islands, like the "Majuli," or middle land, are 130 miles long by 10 to 20 broad. From an elevation of 20 to 30 miles, in fact, this river would undoubtedly present the appearance of a series of long loops.

NOTE.—Mr. Peal's paper will appear in full in *The Canadian Monthly* (Toronto) for May.

BOOK ANNOUNCEMENTS.

Columbian Knowledge Series,—Edited by Professor Todd, of Amherst College. A series of timely, readable, and authoritative monographs on subjects of wide and permanent interest and significance. Each work is intended to be complete in itself. The treatment will be scientific where best suited to the purpose; but the language will be untechnical, and illustrations freely used when appropriate. In no respect will the field of the encyclopædias or of books for the schools be encroached upon. To be issued in 16mo. volumes, neatly and uniformly bound in cloth. 75 cents.

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Total Eclipses of the Sun.—By Mrs. Mabel Loomis Todd.

ERRATUM.—Page 401, first line, for *eves* read *eaves.*

PUBLISHER'S NOTICES.

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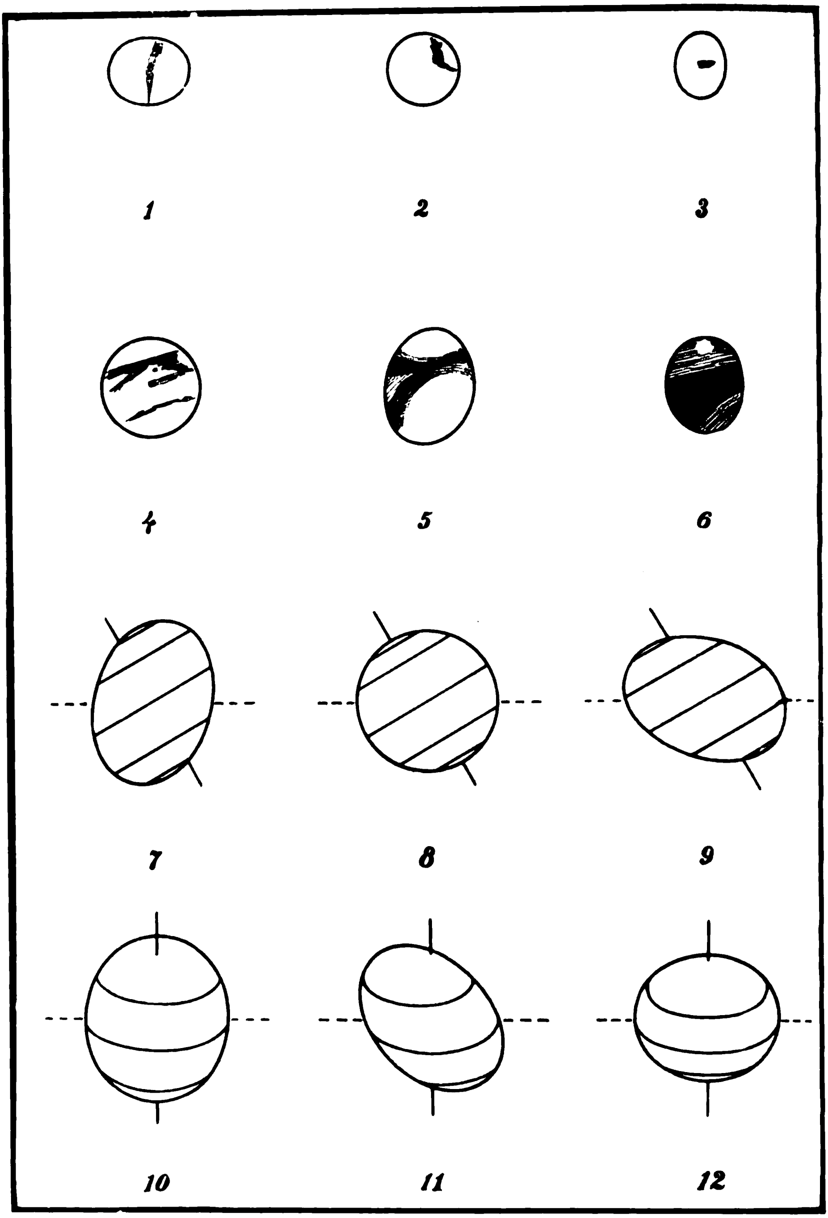
PLATE XXVI.



Jupiter's Outer Satellites.

Astronomy and Astro-Physics.

VOL. XII, No. 6. JUNE, 1893. WHOLE No. 116.

General Astronomy.

THE ROTATION OF JUPITER'S OUTER SATELLITES.*

WILLIAM H. PICKERING.

From what has been already stated in my former papers regarding the forms assumed by the discs of these three bodies, it will not surprise us now to learn that the phenomena presented by their rotation differ in some important particulars from those presented by the rotation of the 1st satellite. Confining our attention for the present to the 3d, the largest and most easily observed of the group, we find that the observed facts may be divided into two distinct classes, those pertaining to the form of the disc, and those pertaining to the detail exhibited by it. These classes we will discuss separately.

In a former paper it was stated that this satellite presents an elliptical phase twice during each revolution in its orbit, at an interval of thirty-four hours after passing each conjunction with the planet. When the satellite is upon the eastern side of its orbit, and presents an elliptical disc, the inclination of the major axis to the orbital plane is clearly marked. The results of twelve series of observations of the position angle of the major axis with regard to the perpendicular to this plane, taken by Mr. Douglass and myself upon seven different nights, is given in the following table. Each series is in general made up of six independent observations.

POSITION-ANGLE OF MAJOR AXIS.

Date	Obs.	P. A.	Dev.	Date	Obs.	P. A.	Dev.
Dec. 23	P	−21°.3	10°.8	Jan. 13	P	−12°.1	1°.6
"	D	−15 .2	4 .7	14	P	− 4 .1	6 .4
"	P	−12 .5	2 .0	15	P	−11 .7	1 .2
31	P	− 9 .4	1 .1	"	P	−11 .5	1 0
Jan. 1	P	− 5 .6	4 .9	29	P	− 5 .8	4 .7
"	D	− 8 .8	1 .7	"	D	− 7 .9	2 .6
					Mean	−10 .5	3 .6

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* Communicated by the author.

These observations indicate a position angle of the axis of — 10°.5. Meteorological conditions have always interfered with our observations of the elliptical phase when it occurred upon the western side of the planet. Nevertheless, it was suspected upon December 28, and distinctly seen by both Mr. Douglass and myself upon January 10 and 11. A single position-angle secured by Mr. Douglass upon January 10 between passing clouds gave the value + 5°.9. An unsatisfactory angle taken by myself upon the evening of March 9, indicated a value of + 37°.4. If these results are correct they would imply a revolution of the axis about the line perpendicular to the orbital plane, in about the same period as the satellite's rotation upon the axis itself. This result would appear at first sight nearly as extraordinary from a theoretical standpoint as the rotation of the satellite about its major axis,—but these points we will discuss later.

Turning now to the other class of observations upon this satellite, we find that as noted in an earlier paper, its disc presents details whose nature can without much difficulty be made out. At first it was supposed to consist of a simple band situated in the northern hemisphere of the satellite. A more careful study, however, indicates for it a somewhat more complicated structure. This marking usually appears forked, the prongs being placed at an angle varying from 30° to 60°. The fork is sometimes turned to the right and sometimes to the left, and sometimes a double fork is seen, giving the marking a shape similar to the letter X turned upon its side. Figure 4 was drawn under very favorable circumstances upon October 15*d* 11^h.5 A. M. T. Probably this drawing and two similar ones made by Mr. Douglass upon the same night give the most accurate idea of the apparent detail of any that we possess. The detail in Figure 5 is taken from a drawing made by Mr. Douglass January 29*d* 8^h.7 A. M. T. Besides the detail the drawing shows the slightly irregular shape of the elliptical disc. The first six drawings are all on a uniform scale of $\frac{1}{400000000}$ or 1 millimeter equals 250 miles. At the mean distance of the planet therefore 9 millimetres equals 1″. From a distance of nine feet the drawings will appear of the same size that the satellites do when in the telescope. The following table gives the position-angle of the axis of the northern edge of the belt referred to the axis of the orbit, upon different dates, also the deviations from the mean. The northern edge of the belt was selected since it was always the darkest and best defined region.

POSITION-ANGLE OF AXIS OF BELT.

Date	Obs.	P. A.	Dev.
Oct. 8	D	+ 10°	5°.5
"	P	+ 14	1 .5
"	P	+ 16	0 .5
"	D	+ 16	0 .5
13	D	+ 11	4 .5
14	P	− 1	16 .5
Oct. 14	P	− 8	23°.5
15	P	+21	5 .5
"	D	+26	8 .5
Dec. 26	P	+21	5 .5
Jan. 1	D	+39	23 .5
16	P	+23	7 .5
	Mean	+15 .5	8 .6

In all of these observations excepting those made upon October 13 and 14, the satellite occupied nearly the same place in its orbit, being between us and Jupiter, and not far from inferior conjunction. This is perhaps unfortunate, but the belt was measured at those times only when it was most readily seen, and it is apparently most conspicuous when the satellite is in this position. We therefore have no means of knowing whether its position angle changes in different portions of its orbit or not. It will be noticed that on comparing the observations of January 1 and 15, in the first table, with those of January 1 and 16, in the second, that the two axes seem to be inclined to one another on those dates between 46° and 35°, and that they are inclined upon opposite sides of the axis of the orbit. These observations were all made with a power of 700 diameters, but 1000 or 1200 would evidently have been much better had we possessed it.*

To show that the belt was a genuine phenomenon, and not an optical illusion, the following experiments were made: The eye-piece was changed and the micrometer turned. The appearance and direction of the belt remaining the same, this showed that there was no defect in the eye-piece. The telescope was turned on opposite sides of the pier, and the satellite viewed at various altitudes. This showed that there was no defect in the objective, and that there was no illusion caused by upper air currents. The observer's head was turned at different angles and both eyes were used alternately to show that there was no defect in the eye. Finally both observers worked independently. Under all circumstances the position-angle remained practically the same within the limits of error, and the belt was clearly defined.

The next question relates to the rate of rotation. Several drawings made upon the night of October 15 (the extremes being at an interval of 4^h 42^m apart), show precisely the same detail. Drawings made upon October 13 and 14 are quite similar, although in the former only the right hand, and in the latter only

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* Our higher powers are not adaptable to the micrometer.

the left hand forks are shown. In all cases the crotch of the fork is near the center of the disc, and the same remark applies to certain drawings made in 1891 in which the fork is also shown. It is possible that the crotch of the fork is an illusion caused by the "diffraction spot." Observations of another kind of detail have, however, been made, which, although too few in number to be of much service at present, yet it is thought may by sufficient repetition in the future serve as a means of settling both the direction and rate of rotation of the satellite. Upon seven nights when the satellite was between us and Jupiter a whitish spot was recorded as visible near its south pole. This spot was conspicuous, It was not brilliant like snow, but sufficiently white to attract the attention. Upon two nights when the satellite was on the further side of the planet, and shortly after passing superior conjunction, the north pole was recorded as slightly more brilliant than the south. When near eastern elongation the limb towards Jupiter was twice recorded as distinctly brighter than the other. It also appeared more sharply curved, (Figure 5.) These observations as far as they go would perhaps imply a period of rotation coinciding with that of the revolution of the satellite in its orbit.

Without attempting as yet to offer any explanation of these results, we will merely recapitulate the facts. (1st), Two observers independently see the disc of the 3d satellite flattened at regularly recurring intervals, independent of the position of the telescope, and they agree as to the direction in which the flattening occurs. This flattening has been noted by several earlier astronomers, among them Secchi, who declared that the ellipse did not always lie in the same direction. (2d), Both observers see a belt upon the satellite in the same position, in the same direction, and with the same character of detail. (3d), The observers agree that the two observations are not particularly difficult ones, requiring unusually keen eye-sight, or unusual atmospheric conditions, but are on the contrary quite evident when the attention is once called to them, and that they can be followed night after night during our clear season.

Turning now to the remaining satellites, we may remark that the detail upon them is much more difficult than that on the 3d, and requires the most favorable conditions for its detection. Of the three, that upon the 1st is probably the easiest, and consists of one or two bands lying in an approximately north and south direction, Figures 11 and 12. These drawings were made upon the nights of October 9, $12^h.0$ and upon Nov. 28, $10^h.4$ A. M. T.

The 2d satellite is undoubtedly the most difficult, and detail was detected upon only one occasion, and that is rather doubtful, Figure 3, October 15, $12^h.0$. The detail upon the 4th is very difficult considering the size of the disc. It usually appears as a broad band, but sometimes as a narrow line, in both cases it is very indistinct, Figure 6, December 29, $9^h.1$. A bright spot, shown in the figure, has several times been recorded near the north pole, and once near the south. The difficulty of observing this satellite is materially increased by its dark color. Its period and direction of rotation upon its axis have not been determined. Its disc has been recorded as shortened in the direction of the plane of its orbit upon fourteen different dates. Upon four of these it was within twenty-four hours of inferior conjunction, upon three it was equally near superior conjunction, upon three it was within twenty-four hours of eastern elongation, upon one it was equally near western elongation, and upon three it was between eastern elongation and inferior conjunction. It was recorded as circular upon eleven other nights.

Regarding the period of rotation of the 2d satellite, our recent observations confirm the period already published, although occasional discrepancies have been noted which do not seem to be due entirely to defective observations. Thus, once or twice the flattening has been but slight when it should have been quite marked, and occasionally the reverse effect has been noted. The amount of the flattening is perhaps more variable than in the case of any of the other satellites. Whether this body really suffers irregularities in the ellipticity of its disc, besides those due to its position in its orbit, must be left for future observations to determine. This question, together with others pertaining to the other satellites, will be treated more in detail and subjected to a fuller discussion elsewhere.

Before closing this series of papers it may be well to bring together all the facts so far recorded, which at first sight seem unaccountable, or were at least, unexpected, when they were first observed. They are as follows:

(*a*). The small density of all these bodies.

(*b*). The retrograde rotation of the 1st.

(*c*). The elongated shape of the 1st.

(*d*). The small density of the 1st as compared with any of the others,—from one-quarter to one-half less.

(*e*). The regularly recurring changes of shape of the discs of the outer satellites, caused apparently by a rotation about their major axes.

(*f*). The change of position angle of the major axis of the 3d, and probably of the 4th, in different portions of their orbits.

(*g*). The considerable inclination of the axis of the belt on the 3d, both with regard to its orbit, and also to its major axis.

(*h*). The fact that in the October and November observations of the 3d satellite, it was once recorded as shortened in a polar direction, and was afterwards upon two nights recorded as "perfectly round," when it so happened as we have recently found, that it was in the position which we have designated as that of maximum ellipticity. Also that the 3d satellite has on some occasions retained its elliptical shape for a longer period than it has at others, as described in my last paper.

(*i*). That the 2d satellite was in the earlier observations frequently recorded as lengthened equatorially, whereas of late no such observation has been made, (see last paper).

(*j*). The apparent irregularities in the period and ellipticity of the 2d and perhaps of the 4th satellite.

(*k*). The occasional irregular non-elliptical shape of the disc of the 3d.

As these bodies seem to differ in so many respects from the larger and better known members of the solar system, it may be interesting to determine how completely these phenomena can be accounted for on Laplace's "ring theory" of evolution. As might be expected some modification of the theory has been found necessary, but the premises are similar and if admitted, it is believed that the conclusions necessarily follow. The premises are as follows:

(1st). Jupiter was formerly surrounded by a series of rings similar to those now surrounding Saturn.

(2d). The direction of rotation of these rings was direct like that of the planet.

(3d). By some force whose cause is not explained, they were shattered, their components uniting but still retaining the same orbit.

(4th). Like the original rings, each satellite still consists of a swarm of meteorites, their consolidation having been intercepted by the enormous tides produced in them by their primary. (See my second paper.)

Having now stated our premises, and described the facts for which our hypothesis must account, we will point out that fact (*a*) is explained by the 4th premise. If the rings had been solid bodies each moving as one piece, it is evident that their outer edges would have moved faster than their inner ones, and had they later been shattered by some cause, and converted into one or more separate satellites, that each satellite would have had a direct rotation like the ring from which it was formed. If, however, the rings were composed of meteorites, as has been shown is necessarily the case with the ring of Saturn their inner edges would travel the faster, and upon their breaking up, the resultant satellites would all have a retrograde rotation, fact (*b*).

When the satellites were formed from the rings, the transformation would not be instantaneous. Presumably several centers of condensation would be formed, which would later unite. Even upon the gradual collision and agglomeration of these masses the spherical form would not at once be assumed, but would only occur after all free translation of the particles among themselves had ceased, fact (*c*). While such relative motion of the particles was maintained, the apparent density of the mass would be less than after it had ceased, and assumed a spherical form. The 1st satellite departs most from the spherical form, fact (*d*).

Dealing with this matter for the moment from the quantitative standpoint, it may be shown that if Jupiter was formerly surrounded by a ring one quarter of a mile in thickness, nine thousand miles in breadth, of the same density as the 1st satellite, and coinciding with its orbit, that on being broken up, if the parts later united to form a satellite, the resultant body would have the same mass, the same size, and the same rate of rotation that we actually find at present. If in the ring form, the meteorites were six or seven times as far apart as we now find them in the satellite, the thickness of the ring would be increased to from fifty to one hundred miles. It is possible that a subsequent gravitational condensation might have influenced the destruction of the ring. Comparing this supposed ring with the outer one of Saturn, we find it would have had three times the diameter. Saturn's ring is ten thousand miles in breadth. Its thickness is unknown, but it has been variously estimated at from forty to one hundred and forty miles.

As any satellite composed of particles free to move among themselves revolves about its primary, there will be a tendency to form tides within it elongating the satellites in the direction of the radius vector. Owing to the rotation of the satellite, the elongation will really make a certain angle with this line. The attraction of the primary acting upon these protuberant regions tends to give the satellite a rotation, the same in direction and period as that of its revolution in its orbit. But a satellite revolving in a retrograde direction is under these circumstances in a position of unstable equilibrium, and the slightest disturbance of its plane of rotation will cause it under this tidal retardation to change its plane with increasing velocity, until it is placed at right angles to the plane of its orbit. After that the change will continue with diminishing intensity until a direct rotation is established coincident with the plane of the orbit. It will be noted that this disturbing force acts at right angles to that producing the precession of the equinoxes. Those who desire a visible illustration of this change of plane can readily obtain it with an ordinary gyroscope. If through condensation, the tides cease before this result is attained, the satellite will continue to rotate in a plane more or less inclined to that of its orbit. The periodically flattened appearance of Jupiter's outer satellites, however, is not due to the tides, which although theoretically some miles in height, could not be seen from the Earth. What applies to the larger planets is upon this theory true also of the smaller ones, including the Earth, which must formerly have revolved in a retrograde direction. Accordingly terrestrial objects now situated to the south of us would then have been found under the northern stars, the Sun itself rising in the west and setting in the east, while the stars moved backwards in their nightly courses. As the plane of rotation changed, the Earth's axis approached, and finally coincided with the plane of its orbit. The Sun then spiralled around the Earth from pole to pole every six months, the tropics reaching the poles, and the polar circles the equator. At present the Earth's equator coincides more nearly with its orbit than does that of Mars, thus further illustrating the same law that applies to the outer planets. Turning now to the Solar System, we find that the inclination of the planes of rotation of the outer satellite systems (145°, 98°, 28°, 2°), and presumably of the outer planets themselves, are arranged in a continuous series, the outer planet, having changed least from its original retrograde rotation. This might imply that the outer planet was formed last, but judging from the analogy of the satellite systems of Jupiter and Saturn, we should rather attribute it to the weakness of the solar tides produced upon a smaller body at that enormous distance.

It has been argued that if such rings once extended around the Sun, similar rings must still be in existence in other parts of the sidereal universe and from their enormous extent should be visible from the Earth, at least as discs, if nothing more. Such rings, however, on account of their vast surface, in proportion to their mass, must almost necessarily be cold bodies, illuminated at a very small angle by their central Sun. We should not then expect that they would be visible, until through some catastrophe they condensed to form a companion Sun. Thus formed they would quite probably be composed of lighter material than the central body, and from this fact, taken in connection with their more recent formation, we should naturally expect that they would present to us a somewhat different spectrum.

Returning from this digression to the satellite system, let us consider the case of a satellite whose plane of rotation had been changed by the tides to a direct motion, but slightly inclined to the plane of its orbit. Let Figure 8 represent such a body. In such a case all of the component meteorites revolve in circular orbits in parallel planes perpendicular to the axis. But owing to this inclination and to the varying attractions of the other satellites, it will be impossible for these orbits to retain their circular form. They will accordingly become slightly elliptical. In so doing, however, their apaxons or the portions of their orbits most distant from the axis will not all be found upon the same side. The swarm must still be symmetrical about its center of gravity. Accordingly for each apaxon found to the right of the axis in the northern hemisphere, there will be a corresponding one found to the left of the axis in the southern. The equatorial plane will then still be circular, and the ellipticity of the orbits will increase steadily as we approach the poles, (Figure 7). Apparently this form necessarily follows upon any distortion of the circular orbits. The perturbation of these elliptical orbits by Jupiter will cause a rapid rotation of the apsides. When these point towards the Earth, the satellite will present a circular disc, (Figure 8). When they have changed their position by 180° they will present the appearance shown in Figure 9, which is similar to that shown in Figure 7, but with a changed position angle. Now these are precisely the changes of shape referred to under facts *e*, *f*, and *g*. Moreover, our micrometer measurements of the 3d satellite show that the diameter when the circular phase is presented is intermediate in length between the two axes when the satellite presents an elliptical disc. The true shape of the satellite is therefore an ellipsoid of three unequal axes.

When the major axis is most inclined to the plane of the orbit, as in Figure 9, the action of Jupiter is to draw the north pole inwards. Although the plane in which this force acts varies in different portions of the orbit, yet the same absolute direction is maintained on the whole, with the result that a precession of the equinoxes is established. But the interesting feature of this precession is that it will take place in the opposite direction to that in which it occurs in the better known members of the solar system, that is to say the rotation will be direct. As a result of this rotation, we shall find that the elliptical phase is not always shown at the same interval after passing conjunction, and that the position-angle of the major axis of the ellipse will vary. If the axis of the satellite, instead of lying in a plane perpendicular to the line of sight, were inclined directly towards, or from us, we should have the series of appearances presented in Figures 10, 11 and 12. That these appearances were presented with more or less distinctness in the cases of the 2d and 3d satellites, in the months of October and November is indicated under facts *h*, *i* and *j*. That such a rotation took place in the case of the 3d satellite is further indicated by our drawings of the belt. In those drawings made early in October, the belt is placed further north than in any made since that time. Moreover, in these earlier showings the belt is concave towards the south, while in the later drawings the concavity is towards the north, and the belt itself is further south. Compare Figures 4 and 5 with Figures 8 and 10. The period of this rotation is unknown, but an examination of our drawings leads me to suspect that it may prove to be about ten weeks. We have no evidence as to its direction, but venture to predict as a test of our theory, that future observations will show it to be direct.

There is one objection which might be raised to this theory, and which therefore requires further elucidation. The precession of the equinoxes, or revolution of the nodes of the orbits of the meteorites, if we prefer that term, requires in the case of the 3d satellite, as we have seen, a period of at least several weeks. The revolution of the apsides of their orbits, on the other hand, is accomplished in a single revolution of the satellite about Jupiter. In the cases of the 2d and 4th satellites, the revolution of the apsides is proportionately still more rapid. If this revolution were caused merely by the perturbations induced by Jupiter itself, the period would necessarily be greater than one revolution of the satellite in its orbit. Probably the most prominent fact bearing upon this question pertains to the density of these bodies. Their density—although small compared to that of most of the members of the solar system, is still so great that we can be pretty certain that the volume of the free space surrounding each meteor does not on the average much exceed ten times the bulk of the meteor itself. This would imply for the meteors a specific gravity of between ten and twenty times that of water. Accordingly they must be in a constant state of collision, and a considerable amount of heat must thus be produced, and lost to the system. This would imply a reduction in the rate of rotation of the satellite as a whole, were it not for the tidal forces engendered by the proximity of their primary. These forces as we have already remarked would also tend to reduce the rate of rotation, until it coincided with that of the revolution of the satellite in its orbit; after this rate was reached, the tides would tend to maintain it. The facts of observation, as far as they go, seem to show that this is the present condition of the 3d satellite. As a consequence, the meteorites although arranged in elliptical orbits, really describe circular paths around their common axis of rotation. Under these circumstances there is less friction among the meteorites themselves, since each would maintain a uniform velocity, than if they actually moved each in an elliptical path. This may therefore be considered as a condition of stable equilibrium which once established would be permanent. The same argument which applies to the rotation of the apsides of the meteorites composing the 3d satellite, applies equally to the cases of the 1st, 2d, and 4th. The period of revolution of the meteorites in their orbits about the axis of the satellite, in each case coincides with the period of revolution of the apsides of these orbits, and consequently each meteorite describes a circular path about the central axis.

There is a peculiarity pertaining to the third satellite which must now be explained—the occasional irregular shape of its disc. Let Figure 7 represent the position of the axes of the satellite when near eastern elongation, then Figure 8 will represent the appearance of the two conjunctions, and Figure 9 that of western elongation. An examination of these figures will show that although the southern hemisphere is in one part of the orbit nearer to Jupiter than the northern, that on the whole the northern is nearer, and is therefore more attracted by the planet. This condition of affairs will continue until by the precession of the nodes the axis of the satellite is turned the other way. As a result, we should expect that during half the period of precession the northern hemisphere of the satellite would be drawn rather nearer the planet than its mean position, and that during the remainder of the time the other hemisphere would be similarly distorted (fact *k*). Figure 5 shows the distortion of the disc of the 3rd satellite as it appeared to me upon January 29, and also upon December 31, when the satellite was also near eastern elongation. Since the apsides of both the 2d and 4th satellites complete approximately two revolutions during one revolution of the satellites in their orbits, in their cases no such distortion should occur. None has hitherto been recorded.

All of the observed facts have now been accounted for, and I have endeavored to show, not only that we may thus explain all the facts observed, but also, admitting the premises, that at some time in the history of the system, all of the more important of these phenomena must necessarily have presented themselves. In this paper I have made no attempt to treat the matter from a mathematical standpoint. Such an attempt would indeed be quite useless, with the very insufficient data at present at our disposal. As stated in a former paper, this lack is in part due to my absence from the Observatory, and in part to the pressure of routine work. It is also very largely due, especially as regards the three outer satellites, to the fact that at the time our observations were made, we had not the slightest comprehension of the nature of the phenomena that were presented to our view. The facts were collected as they were observed, and recorded, without any theory whatever to guide us, and many valuable opportunities were thus undoubtedly lost, merely from the fact that we did not know what phenomena to expect, or to what points we could most profitably direct our attention. This year's observations have, however, put us in possession of a theory, and it is hoped that the observations of another year may supply at least a portion of the requisite numerical data. As I am about to return to Cambridge temporarily, where the climate is such, that this class of observation is entirely out of the question, I have collected together the following notes, hoping that they may be of assistance to those astronomically more favorably situated. They consist merely of a series of suggestions regarding the points to which the attention can be most profitably directed in the case of each satellite, together with a letter intended to indicate the difficulty of the observation. Thus, those observers, who are located under such climatic conditions that they cannot profitably employ a magnification greater than 400 diameters, may devote their attention to the observations marked "*a*," but it would be a waste of time for them to attempt any of the others. Those observers who can employ 700 diameters may attempt those observations marked both "*b*" and "*c*," but they will find the latter difficult, and for these can most profitably employ a power of 1000 diameters. I have classified these observations by the magnifying power, rather than by the aperture of the telescope, because as we have shown, they can be repeated by any one possessing a telescope of 13 inches aperture, under favorable atmospheric conditions, whereas the largest aperture would be useless were the climate unfavorable. When the small letter is in italic, the observation should be made, if possible, whenever the satellite is observed.

1ST SATELLITE.

a. Color as compared with 2d and 3d. This has been thought to vary. It can be studied best when near one of these bodies, but only when the sky is perfectly clear from haze.

a. Position angle of the major axes when near maximum ellipticity.

b. Ratio of major and minor axes, both by micrometer and estimation, when at maximum ellipticity. The ellipticity of Jupiter makes an excellent standard for purposes of estimation, and may be called 5, a circular phase being indicated by 0.

b. Determination of period by observation of circular phase.

c. Shape of disc when of minimum phase.

c. Distortion of disc from elliptical shape. I have never been able to see this phenomenon myself, although it has been recorded once or twice by Mr. Douglass.

c. Study of detail by means of drawings.

2D SATELLITE.

a. Color as compared with 1st and 3d.

b. Ratio, probably best by estimation, of the major and minor axes of the disc.

b. When occulted with phase near maximum ellipticity, note change of position-angle of axes, caused by the refraction of Jupiter's atmosphere.

c. Position-angle of major axis at times of maximum ellipticity.

c. Study of detail,—very difficult.

3D SATELLITE.

a. Determination of the refraction of Jupiter's atmosphere when this satellite is occulted by the dark limb. See my third paper. Before opposition the second and fourth contacts can be observed after opposition the first and third.

a. Color as compared with 1st and 2d satellites.

a. Position-angle of major axis.

a. Ratio of major and minor axis by micrometer, and also by estimation.

a. Drawings of detail. Study of rotation by observation of bright polar spots, and varying relative brightness of limbs.

b. Distortion of disc from the elliptical shape. Precise nature and position-angle of the distortion.

b. Position-angle of belt.

c. Estimation of location of belt between the northern and southern poles of its axis. Direction of its curvature.

4TH SATELLITE.

a. Color as compared with the brightest parts of Jupiter taken as a standard of white. This can only be satisfactorily observed when near the planet.

b. Ratio of major and minor axes. This can probably be best obtained by estimation, but the micrometer might be tried.

b. Study of rotation by observations of the bright polar spots.

c. Position-angle of the major axis.

c. Study of surface as to detail, and also as to relative color of different regions.

c. Distortion of disc from elliptical shape, when at maximum ellipticity. This has never been noticed here, but it is desirable to settle the question of its non-existence.

In the above list of suggestions, I have included under each satellite only those observations which our experience here has led me to think it is practicable to make. With the exception noted, each of these observations has been made in Arequipa this past year.

AREQUIPA, Peru, March 20, 1893.

THE ORBIT OF 9 ARGUS. (β 101).*

S. W. BURNHAM.

This close pair was discovered with the 6-inch refractor in 1873. The attention of Baron Dembowski was called to it, and in 1875 it was measured by that distinguished observer. It was evident in the course of a very few years that it was a binary in rapid movement. Since that time the angular motion has been nearly 180°. For some years it has been a difficult pair to measure, and at the time of my last observations in 1892, it was a hard star with the 36-inch.

Last year Professor Glasenapp computed the orbit of this pair (*Monthly Notices*, June 1892) using my last measures at Mt. Hamilton, and found a period of 40.54 years. This orbit repres-

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* Communicated by the author.

ented all the measures very satisfactorily with the single exception of the distance in the last measures of 1892. I found the distance to be 0″.22, and the orbit required that the distance at this time should be 0″.38. The largest error in the other observed distances was only 0″.07. The measures of 1889-91 did not show any diminution in the distance, and it would be very natural for any one but the observer to assume that the measured distance in 1892 was too small, and that it should be made to conform to the previous observations. But having made these measures on three different nights, and having looked at the star on several other occasions when it was too difficult with the then conditions to be well measured, I am able to say with confidence that my distance is substantially correct, and certainly not sensibly too large. One could not possibly make an error of 0″.16 in estimating, without the use of the micrometer at all, a distance of 0″.22. The error of estimation in such a pair ought not to much exceed 0″.05 where the observer has had considerable experience in this kind of work. I feel confident that at this time the distance of the components was not greater than 0″.25.

If this is the fact, it is obvious that Glasenapp's ellipse is incorrect, notwithstanding it represents all the other measures very perfectly, and that his period is much too long.

He has used the following measures:

Date	P	D	*n*	
1875.71	289°.4	0″.46	3	Δ
78.50	302 .2	0 .45	4	Cin—β
79.68	306 .2	0 .38	2	Hl
82.21	319 .7	0 .35	4	Sp
83.11	336 .2	0 .30	1	β
89.08	76 .4	0 .34	4	β
90.22	83 .8	0 .34	6	β—Sp
91.06	91 .5	0 .34	4	β—Sp
92.05	98 .7	0 .22	3	β

Glasenapp's orbit is shown by the large ellipse on the accompanying diagram, and the nine observed positions given above are accurately laid down to scale. It will be seen that this ellipse represents all the measures except the last, where the measured distance appears to be altogether wrong. As I have already said, I have every confidence in the substantial accuracy of this result, as well from the appearance of the star, which is perfectly remembered at this time, as from the micrometrical measures themselves. I have therefore, endeavored to ascertain whether some other ellipse could not be found which would repesent the measures of 1891 equally as well as those made previous to that time. There was no difficulty in describing an ellipse which represented quite as well as the other all the observations down to 1891, and at the same time made the last distance in 1892 entirely satisfactory. As this ellipse was finally rejected, it is not shown on the diagram. The following are the corrections which must be applied to the actual measures to make them conform to the respective apparent orbits:

	G		β	
1875.71	−1°.9	−0.03	0°.0	+0″.01
78.50	−1 .1	−0.03	−1 .0	0 .00
79.68	+1 .2	+0.02	+0 .9	+0 .02
82.21	+5 .2	−0.03	+6 .8	−0 .05
83.11	−2 .5	−0.01	0 .0	−0 .03
89.08	−2 .8	−0.07	−3 .5	−0 .01
90.22	+1 .6	−0.02	−2 .0	−0 .02
91.06	+0 .6	+0 01	−2 .5	0 .00
92.05	0 .0	+0.16	0 .0	+0 .03

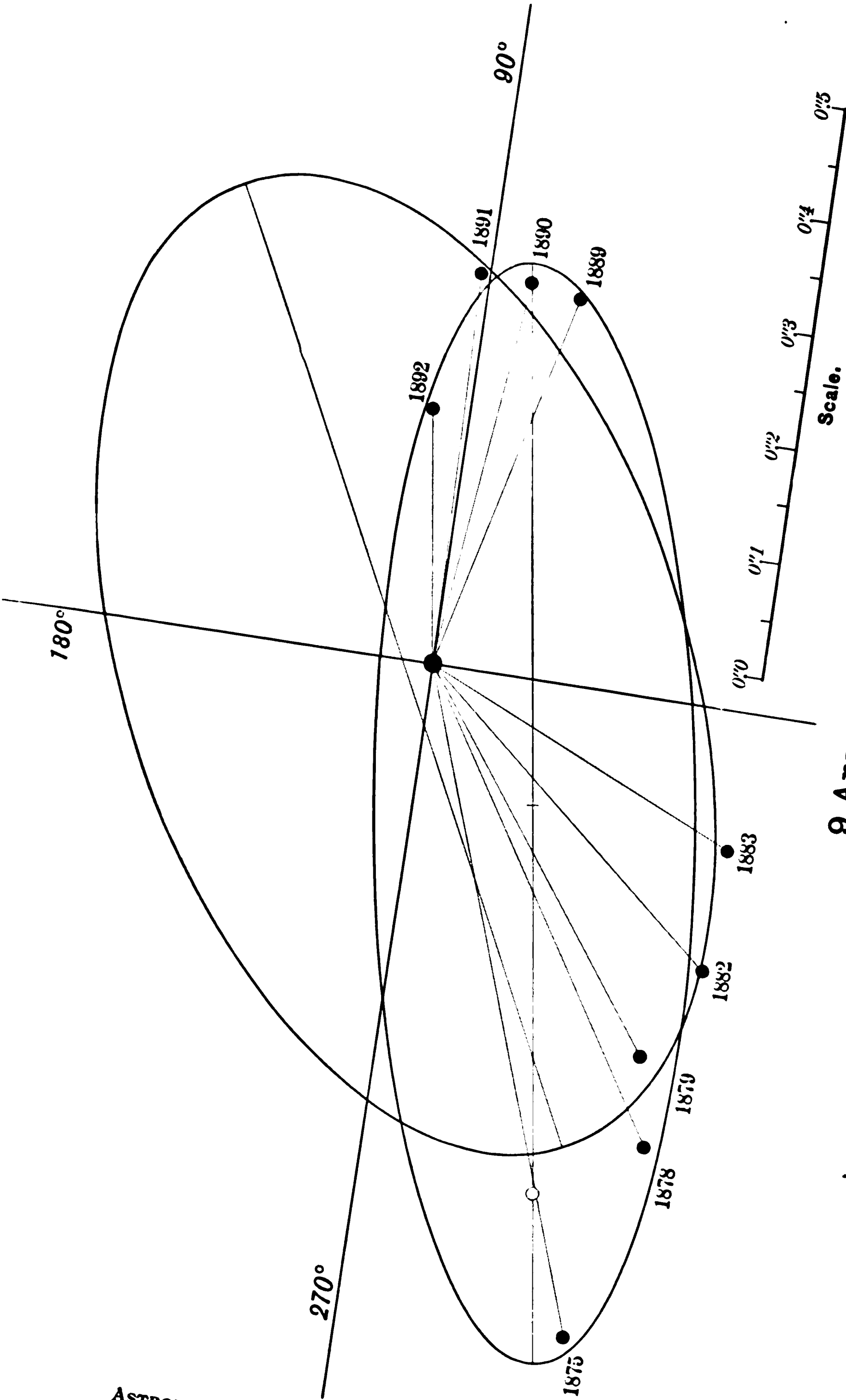
It will be observed that these ellipses are entirely different, and have in fact, nothing in common. But one orbit is known of a binary system where the eccentricity is so small as that of the larger of these ellipses, while in the other the eccentricity is one of the largest known. The following elements are derived from the apparent orbits:

	G	β
P =	40.54 years	20.0 years.
T =	1844.02	1892.8
e =	0.09	0.72

If the first is correct, this should now be a very easy pair, as the distance would be between 0″.4 and 0″.5; on the other hand in the other ellipse the distance at this time would be so small, that the star would be apparently single in nearly every telescope in the world. I have examined this pair twice with the 18½-inch refractor of the Dearborn Observatory within the last few weeks. The seeing was not very good on either occasion, and perhaps an exceedingly close pair would not have been seen. No certain elongation could de detected with any power, and there seemed to be no doubt of its being very close or practically single with ordinary instruments.

Certainly one would be justified in assuming from the agreement of the theory with the observations, that there was hardly any question that the smaller ellipse was very near the truth, and that nothing better could be done with the present data. But when we come to examine the question in another way, we see at once that notwithstanding this beautiful agreement, the result is impossible, and that the assumed premises must be somewhere fatally defective. This pair was discovered on March 11, 1873, and, therefore, with a period of 20 years it should have completed

PLATE XXVII.



9 Argus. β 101.

one revolution at the date 1893.19, while as a matter of fact at the beginning of 1892 the companion was still about 180° from the place where it was first seen. The angular motion in this part of the orbit would necessarily be very rapid, but the period must exceed twenty years, as otherwise at this time the companion would be in the fourth quadrant, and it would be readily seen with instruments as small as that with which it was discovered. I have given the result of this investigation, because it is a good illustration of how unsafe it is to rely upon a favoroble showing of this character, without some other independent evidence. Many astronomical castles in the air have been reared upon beautiful and elaborate columns of residuals which appeared for the time to be without defect or weakness.

While this ellipse is satisfactory so far as the observations which have been used are concerned, evidently some important consideration has been over-looked which should have entered into the calculation. Referring to my *Second Catalogue of New Double Stars* (*Monthly Notices*, May, 1873) where this pair was first published, it will be seen that the estimated distance is given 0″.7, and the angle 120° (300°), the components being considered of equal magnitude. I have not been able to consult my original observing book of that date, but I find in the *Astronomical Register* for June 1873 an article on this star written by me in which it is stated, "the distance I estimate from 0″.5 to 0″.7." I think it is safe to assume that the probable error of the estimate would place the star not far from this mean. In this connection I may mention that in a later number of the same journal (*Ast. Reg.* Feb. 1876) I gave the result of a comparison of all my estimates of the distances of double stars discovered by me down to that time, with the subsequent measures of Dembowski, and from this it appeared that in estimating the distance of pairs where it did not exceed 1″, and of course many of them would be less than 0″.5, the mean error was 0″.11. Therefore I think we may say that the real distance of 9 Argus at the time of discovery was about 0″.6.

For the purpose of getting all the information possible concerning the relative position of the components in the early part of the observed revolution, it is desirable to examine critically the first measures that were made. We find the following individual measures by Dembowski, with the mean result which he adopted:

1875.244	289°.6	Cuneata
75.249	289 .9	0″.58
76.071	(314 .0)	0 .35 al piu
76.263	288 .8	0 .44 cuneo
1875.71	289°.4	0″.46

This mean is used by Glasenapp in his orbit, and by me in drawing the twenty year ellipse. Now, it is clear that in a rapidly moving pair like this, observations in different years should not be combined unless for exceptional reasons, and that the two positions in 1875 should stand by themselves. From all the evidence it would seem that the measured distance of 0″.58 was probably about right, and I have therefore adopted the mean of these two measures:

1875.24 P = 289°.7 D = 0″.58

The angles in 1876 differ so much that no use can be made of them. A mean cannot be used where the discrepancy is so large, and the only safe way is to reject them altogether.

We have now additional data for a new apparant orbit which will necessarily be wholly unlike the large ellipse, and in some respects will differ from the other. The new position from Dembowski's measures in 1875, given above, is laid down on the diagram, and all of the measures used are represented by dark circles. The position from the mean of all Dembowski's observations, which is now rejected, is shown by the white circle.

The ellipse shown on the diagram was then carefully drawn to represent in the best possible way all of these observed positions, and make the areas proportional to the times. How successfully this has been done will be seen from the following corrections which have to be applied to the observations to make them conform to this orbit:

1875.24	0°.0	+ 0″.01
78.50	− 1 .7	+ 0 .04
79.68	− 0 .5	+ 0 .05
82.21	+ 5 .0	− 0 .04
83.11	0 .0	− 0 .04
89.08	− 3 .8	− 0 .01
90.22	− 1 .8	+ 0 .02
91.06	− 2 .7	0 .00
92.05	0 .0	+ 0 .02

From this ellipse we get directly the following elements:

P = 23.3 years.
T = 1892.7
e = 0.68

According to this orbit, the position-angle at the time of discovery (1873.19) was 283°.5, and the distance 0″.58. This agrees well with my estimates at that time, and all the subsequent measures, including the last observations at Mt. Hamilton, are satisfactorily represented.

We have not long to wait to determine whether or not this orbit is generally accurate. The enormous angular velocity from the date of the last measures, should in the two years following that time, carry the companion over an arc of about 180°, so that when this pair can be observed again at the beginning of 1894, the position-angle should be a little more than 270°, and the distance about 0″.35. This will make it easily measurable with ordinary telescopes, and it can then be determined at once what, if any, corrections are necessary in this ellipse.

CHICAGO, April 27.

NOTE.—Since the foregoing was written and forwarded to the editor, I have shown the original diagram to my friend, Dr. T. J. J. See of the University of Chicago, and he has kindly computed from this apparent ellipse the elements of the real orbit by the method of Klinkerfues. Dr. See finds from the ellipse shown on the diagram the following:

ELEMENTS OF 9 ARGUS. β 101.

$P = 23.377$ years
$T = 1892.706$
$e = 0.68$
$i = 76^\circ.87$
$\Omega = 95\ .75$
$\pi - \Omega = 73\ .92$
$a = 0''.612$
$n = +\,15.3998$

It will be seen that the elements previously obtained directly from the diagram are practically identical, as far as they go, with those deduced by the more rigorous method used by Dr. See.

ORBIT OF A NEW RAPID BINARY STAR 20 PERSEI = β 524.[*]

MY DEAR SIR:

As soon as I received your letter with the observations of 20 Persei ($\alpha = 2^h\,47^m.4$, $\delta = +\,37^\circ\ 56'$: 1900) I determined the elements of the true orbit. Here are the observations of 20 Persei, which you have had the kindness to send to me:

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[*] A letter from Professor S. Glasenapp to S. W. Burnham.

t	θ	ρ	Observer	[illegible]
1878.72	156°.0	0″.25	[illegible]	[illegible]
80.53	141 .4	0 .22	[illegible]	[illegible]
89.59	291 .3	0 .17	[illegible]	[illegible]
90.61	287 .6	[illegible]	[illegible]	[illegible]
91.79	281 .7	0 .15	[illegible]	[illegible]

From your drawing I have obtained the following geometrical elements:

$$\begin{aligned} \omega &= 133^\circ.03 \\ \lambda &= 263\ .70 \\ i &= 73\ .62 \\ e &= 0\ .475 \quad (\varphi = 28^\circ.[illegible] \\ a &= 0''.25 \end{aligned}$$

The dynamical elements T and U were evaluated from the two first observations and the last one by means of the following formula:

$$T = \frac{t' + t}{2} - \frac{M' + M}{M' - M} \cdot \frac{t' - t}{2}$$

$$n = \frac{M' - M}{t' - t}\,;\ U = \frac{360^\circ}{n}$$

where M and t represent the mean anomaly and the time for the mean of the first two observations, and M', t' — the same quantities for the last observation. Thus, we obtained:

$$\begin{aligned} T_0 &= 1885.22 \\ U_0 &= 21.75 \text{ years.} \\ n_0 &= -16^\circ.547 \end{aligned}$$

To find the corrections of the dynamical elements from all observations, I have proceeded in the following way:

Let T_0 and n_0 be the approximate values of the periastron passage, and of the mean motion; dT_0 and dn_0 — their corrections; T and n — the most probable values of the periastron passage and of the mean motion. Then we have:

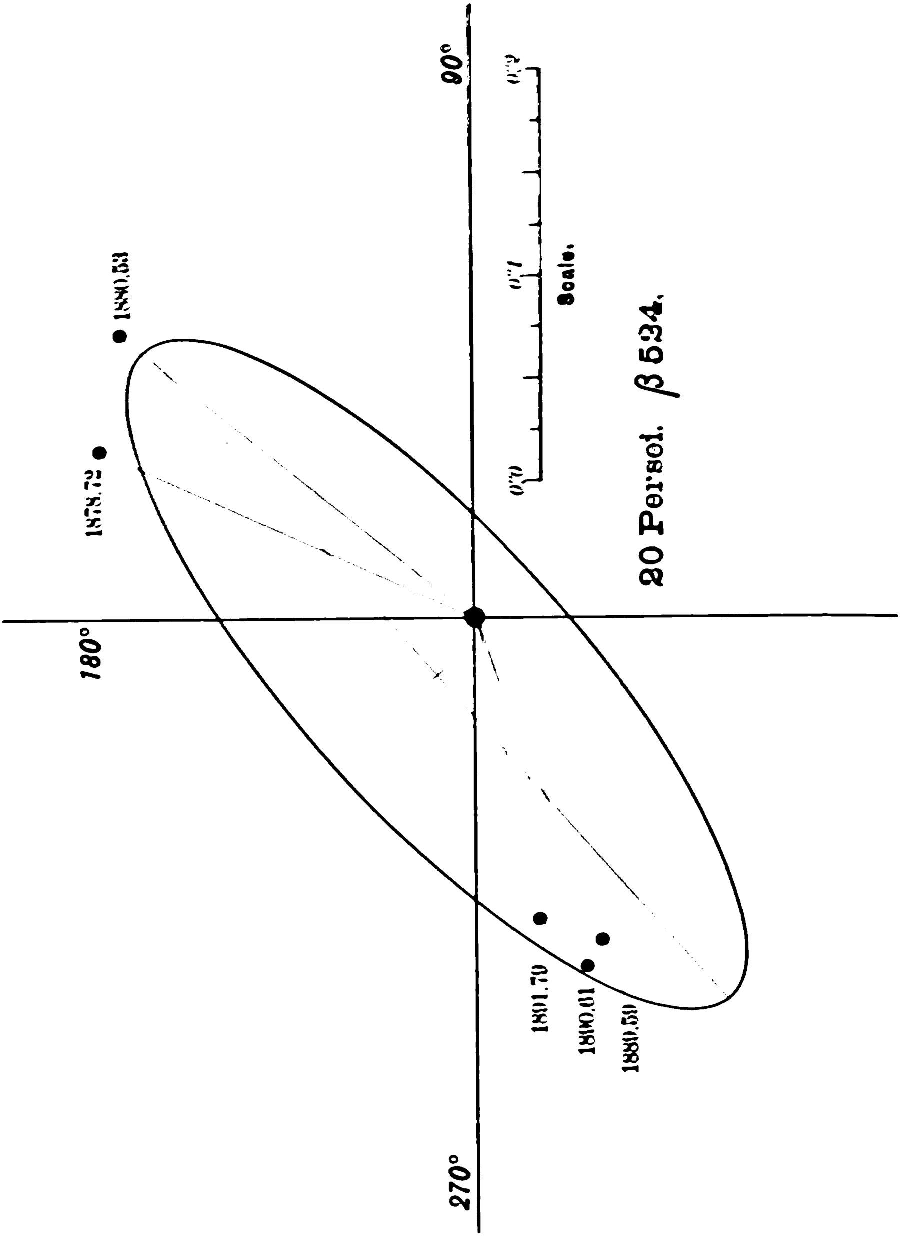
$$\begin{aligned} T &= T_0 + dT_0 \\ n &= n_0 + dn_0 \end{aligned} \qquad \text{(A)}$$

If the geometrical elements obtained were considered as perfectly exact, and if the measures were also absolutely correct, the well known equation:

$$E - e \sin E = n(t - T) \qquad \text{(B)}$$

would be exactly satisfied. But we know only approximate values of T and n, and the measures always contain errors; therefore this equation will be not generally exactly satisfied. The difference between $E - e \sin E$ and $n(t - T)$ may be considered as a

PLATE XXVII a.



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function of the unknown corrections of the elements and of the occasional errors of observation.

If we introduce in the last equation the values of T and n from the above relations (A), we will have

$$E - e \sin E = (n_0 + dn_0)\,[t - (T_0 + dT_0)]$$

or:

$$-(n_0 + dn_0)dT_0 + (t - T_0)dn_0 + n_0(t - T_0) - (E - e \sin E) = 0$$

If we put for brevity:

$$Z = -(n_0 + dn_0)dT_0$$
$$w = n_0(t - T_0) - (E - e \sin E)$$

we will have

$$Z + (t - T_0)\,dn_0 + w = 0 \qquad \text{(C)}$$

The excentric anomaly must be calculated with the given elements and the observed θ by the formula:

$$\text{tang}(v + \lambda) = \text{tang}(\theta - \Omega) \sec i$$
$$\text{tang}\frac{E}{2} = \text{tang}\left(45° - \frac{\varphi}{2}\right)\text{tang}\,\frac{v}{2}$$
$$e = \sin \varphi$$

The values of $t - T_0$ and w are to be found in the next table:

t	$t - T$	θ_0	$E - e \sin E$	$n_0(t - T_0)$	w
1878.72	− 6.24	156°.0	116°.29	107°.55	− 8°.74
80.53	− 4.43	141 .4	68 .97	77 .61	+ 8 .64
89.59	+ 4.63	291 .3	269 .99	287 .69	+ 17 .70
90.61	+ 5.65	287 .6	262 .11	270 .81	+ 8 .70
91.79	+ 6.83	281 .7	251 .33	251 .28	− 0 .05

From these data we obtain the following equations of condition (C):

$$1 - 6.24\,dn_0 - 8.74 = 0$$
$$1 - 4.43\,dn_0 + 8.64 = 0$$
$$1 + 4.63\,dn_0 + 17.70 = 0$$
$$1 + 5.65\,dn_0 + 8.70 = 0$$
$$1 + 6.83\,dn_0 - 0.05 = 0$$

The solution of these equations by the method of least squares gives us the following normal equations:

$$5Z + 5.14dn_0 + 26.25 = 0$$
$$+ 5.14\,Z + 155.57dn_0 + 144.73 = 0$$

from which we obtain:

$$Z = -4.45$$
$$dn_0 = -0°.783$$

and finally:

$$n = n_0 + dn_0 = -17^\circ.330$$

$$dT = \frac{+4.45}{-17.330} = -0.26 \text{ years.}$$

Hence, the dynamical elements obtain the following values:

$$T = 1885.22 - 0.26 = 1884.96$$

$$n = -17^\circ.330; \quad U = 20.77 \text{ years}$$

and the system of elements of the true orbit of 20 Persei:

$T = 1884.96$
$U = 20.77$ years
$n = -17^\circ.330$
$\Omega = 133.03$
$\lambda = 263.70$
$i = 73.62$
$e = 0.478 \quad (\varphi = 28^\circ\ 55)$
$a = 0''.25$

We give here the comparison of these elements with the observations:

t	θ_o	θ_c	$\theta_o - \theta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$
1878.72	156°.0	153°.0	+ 3°.0	0''.25	0''.21	+ 0''.04
80.53	141 .4	143 .5	− 2 .1	0 .22	0 .24	− 0 .02
89.59	291 .3	295 .4	− 4 .1	0 .17	0 .20	− 0 .03
90.61	287 .6	287 .6	0 .0	0 .18	0 .18	0
91.79	281 .7	275 .3	+ 6 .4	0 .15	0 .15	0

From a simple inspection of the residuals it seems that the signs of the residuals $\theta_o - \theta_c$ recur about as might be expected when the elements are inexact; but as the last three observations lie very near to each other, we must consider the residuals and their signs having an accidental character.

The number of observations is too small to obtain corrections of the elements. It is better to wait for new observations which can be made with large telescopes after the next two or three years.

An ephemeris of the satellite of 20 Persei is given in the next table:

Ephemeris of Persei = β 524.

t	θ	ρ
1893.83	238°	0''.106
1894.83	214	0 .105
1895.83	192	0 .120
1896.83	176	0 .144
1897.83	165	0 .169
1898.83	157	0 .197
1899.83	151	0 .219
1900.83	146	0 .233
1901.83	141	0 .235
1902.83	136	0 .230

Professor S. GLASENAPP.

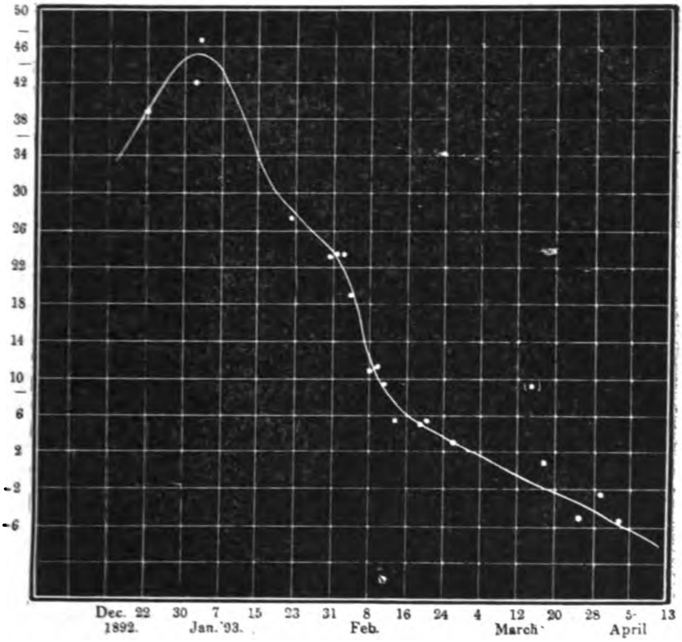
OBSERVATORY Georgiewskaja Abastuman.

THE NEW VARIABLE STAR IN ARIES.[*]

PROFESSOR S. GLASENAPP.

In Asttronomy and Astro-Physics for October, 1892, p. 251, is printed a sketch of the stars surrounding the new variable star in Aries which I believe may be called U Arietis. From December 22, 1892, to April 2, 1893, I have observed this star on 21 nights, and have obtained a well marked maximum on January 1, 1893. Four stars were selected for comparison; their positions were estimated from the above mentioned sketch as follows:

a:	$\alpha = 3^h\ 5.0^m$	$\delta = +14^\circ\ 15'$
b:	$\alpha = 3\ \ 5\ 2$	$\delta = +14\ \ 7$
d:	$\alpha = 3\ \ 4.6$	$\delta = +14\ \ 27$
f:	$\alpha = 3\ \ 4.6$	$\delta = +14\ \ 26.8$



Variation in brightness of U Arietis.

The two stars *a* and *b* may be found in the Argelander's Bonner Durchmusterung, namely:

a = BD. 14° 527	$\alpha = 3^h\ 3^m\ 4\ 7^s$	$\delta = +14^\circ\ 8.7'$	(9.5^m)	for 1855.0
b = BD. 14 529	$\alpha = 3\ \ 3\ 20.3$	$\delta = +14\ \ 1.7$	$(9.5\ )$	

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[*] Communicated by the author.

From the observations made at Abastuman I have deduced the following scale of brightness of the comparison stars by Argelander's method "Hufenschätzungen":

$a = 36.9$ "Stufe" or degrees.
$b = 33.0$ " "
$d = 6.1$ " "
$f = 0.0$ " "

Between b and d there are no suitable stars for comparison in the field of the 9-inch refractor; therefore I was obliged to content myself with the large difference of light between these two stars. I had it in view to take a fifth star for comparison and selected the following:

c: $\alpha = 3^h\ 4.8^m$ $\delta = +14^\circ\ 43'$

but it is a double star, which might make the comparison uncertain; and for this reason it was omitted.

The star f, which lies very near to d and follows it, is a very faint star.

The variable U Arietis is determined by the following co-ordinates:

$\alpha = 3^h\ 4.9^m$ $\delta = +14^\circ\ 24'$

The following is a copy of the observations:

Date.			Mean time of Abastuman. h	m	Observations.	D. °
1882.	Dec.	22	11	15	U 6a; U 12b; U is read.	39.0
1893.	Jan.	1	7	0	U 9a; U 15b; U is read.	42.0
		2	9	46	U 15a; U 20b.	47.5
		22	7	30	a7 U; U 1b	27.0
		30	8	27	a10 U; b 4 U.	23.0
	Feb.	1	7	27	a9 U; b 4 U.	23.5
		2	8	39	a10 U; b 3 U.	22.5
		4	8	50	a15 U; b 7 U.	19.0
		8	7	45	a > U; b 12 U.	11.0
		9	9	6	a25 U; b 10 U; U 2d.	11 2
		10	8	52	a25-30 U; b 12 U; d2 U.	9.7
		13	7	3	a30 U; b 15 U; d3 U; U 5f.	5.9
		19	7	10	a35 U; b 17 U; U d; U 6f.	5.1
		20	7	20	a35 U; b 20 U; U 1d; U 9f.	5.4
		26	7	25	d4 U; moonshine; thin clouds.	2.7
	Mch.	15	6	47	a25-30 U; clouds, inexact.	(9.4)
		17	7	20	d5 U; U f; good observation.	0.8
		18	7	30	U is visible, but clouds do not permit to make a valuable estimation.	
		25	8	10	d and f are visible, U is not visible; full moon; I suppose that U can not be brighter than U = f — 5.	— 5.0
		39	7	40	f2 — 3 U; strong moonlight.	— 2.5
	April	2	7	55	f5 — 6 U; U is not continually visible.	— 5.5

These observations made with the nine-inch refractor, using the smallest power, about 40. The last column contains the observed brightness of U Arietis in degrees of the scale.

It must be observed that until Feb. 8 the difference between *a* and *b* was estimated as equal to 6.4 degrees (Stufe) and after this time as equal to 15.7 degrees. I cannot explain the cause of this discordance; possibly the star *a* is also a variable.

I have plotted the observed brightness of U Arietis on millimeter paper, and have obtained the curve shown in the diagram. The maximum evidently occurs at the beginning of the year :

Max. = Jan. 1, 1893.

The minimum could not be observed because the star diminishing in brightness is gone in the evening twilight.

The double star *c* was measured in two evenings; the results will be published with all the measures made by me in Abastuman.

The longitude of the Georgiewsksja Observatory in Abastuman is equal to $2^h\ 51^m\ 19^s.5$ east of Greenwich.

EXPERIMENTS IN ELECTRIC LIGHTING.[*]

HEBBERT A. HOWE.

Electric lamps of one candle power are now used so universally upon astronomical instruments that the results of experiments and research concerning the best methods of lighting them may be acceptable to those who have not studied the matter particularly. Three available sources of electricity suggest themselves at once, viz., the primary battery, the secondary battery, and the alternating current, which is so widely used for illuminating buildings. They will be discussed in order.

1. *The Primary Battery.*—The carbon-zinc batteries are thought to be the best for lighting purposes. However all forms of them need constant care, if they are to be kept in a satisfactory state of efficiency. The Taylor cell (Taylor Battery Co.—39 Dey St., N. Y.) is an excellent one, having an E. M. F. of 1.9 volts, and an internal resistance of only 0.08 of an ohm. A No. 2 cell, 8 × 6 inches in size, replaces 30 gravity cells, in running an Edison phonograph: three such furnish sufficient power to drive a sewing machine. The zinc is thoroughly amalgamated, and does not wast away, when the battery is idle. As there are no creeping salts the battery is clean. A No. 2 cell costs $2.50: its porous cup holds one pint of the depolarizing solution, which is good for 80 ampere hours, at a cost of four cents and a fraction. The fumes

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[*] Communicated by the author.

of this battery are, however, very disagreeable: on this account it is well to enclose it in a box, from which a tube leads out of doors.

Another form of battery, which is said to give a powerful and steady current for a long time, and to be inexpensive in maintenance, is described in detail, with drawings, by Lieutenant C. D. Parkhurst in Bubier's Popular Electrician for August and September, 1892.

2. *The Secondary Battery.*—This is used by some who are so located that it can be charged easily by a direct current. I have never used storage batteries and do not know how true the statement is that the services of an expert are required to keep them in order. They are commonly reputed to be expensive and troublesome. It is claimed that the speedy disintegration to which such batteries are liable is obviated in a new form manufactured by the Ford-Washburn Electric Co., of Cleveland, O. There are no plates in this battery to buckle; the active material is contained in porous cups of special manufacture; the internal resistance is not far from 0.05 of an ohm. The battery is not injured by short circuiting, and remains in good condition for an indefinite period, when on an open circuit. Omnibuses are now lighted in London, with entire success by storage batteries weighing but eight pounds.

3. *The Alternating Current.*—If the Observatory be illuminated by the ordinary incandescent lamps on an alternating current, the house current may be used for the little lamps. This will be found to be the most satisfactory of the three methods. If the wire leading to any one of the house lamps be tapped, and one of the 1 c. p. lamps be introduced into the circuit, so that the current will flow through both of the lamps, the light given by the larger one will be decidedly dimmed, and the little one will glow. If the house lamp be now taken out, and a resistance box, having a capacity of from a hundred ohms downward, be inserted into the circuit with the little lamp, various degrees of brightness may be given to the little lamp by varying the resistance. After a series of experiments with resistance coils made of German silver wires ranging from No. 22 to No. 30, I came to the conclusion that the mere insertion of resistance did not give a satisfactory solution of the problem. Too much energy was consumed in heating the resistance coils: the cost of running a 1 c. p. lamp was not far from that of using a 16. c. p. lamp. Mr. Elbert G. Richardson, a Denver electrician, then offered to build a little transformer for me, to reduce the voltage of the house current

down to suit the 1 c. p. lamps. This converter is so simple, that I beg to describe it in detail. The core is a ring of ordinary stove wire, about 4 inches in external diameter, and 2½ inches in internal diameter. Such a ring may be made by winding the wire loosely around a good sized bottle. If the wire be rusty, so much the better, except for the man who does the winding. Bright wire may be varnished, and allowed to dry, before winding. Pieces of tissue paper occasionally inserted during the winding, for purposes of insulation, will add to the efficiency of the converter. Insulating tape is then wound around the core, covering the mass of wire completely. 1200 turns of double-cotton-covered copper wire No. 28 are wound over this (as one winds a string around his finger), the plane of each turn being perpendicular to the direction in which the stove wire underneath runs. The whole is next covered with insulating tape, except the two ends of the No. 28 wire are left out to be attached to the binding posts. The coil just put on is the primary, through which the house current is to run. The secondary coil of No. 17 double-cotton-covered copper wire is now to be wound on, in the same way as the primary wire. The number of turns of this wire is found by the following proportion.

The voltage of the primary current : that of the secondary current :: the number of turns of the primary wire : is to the number of turns of the secondary wire. The house current, which is to be utilized in the primary circuit has an E. M. F. of 50 volts usually. The voltage of Edison 1 c. p. lamps varies from 4 to 6 volts. If we wish the secondary current to have an E. M. F. of 6 volts, we have the following proportion for finding the number of turns of the secondary wire:

$$50 \text{ volts} : 6 \text{ volts} :: 1200 \text{ turns} : x\ (= 144) \text{ turns}.$$

The ends of the secondary wire are now attached to two binding posts, and the converter is ready for use. The wires leading to any one of the house lamps may be connected with the binding posts joined to the primary coil of the converter, while the wires from a 1 c. p. lamp are connected with the binding posts which are the terminals of the secondary coil.

It is easy to arrange matters by a two point switch, so that the current will either feed the house lamp, or the converter, at will; both can be run at the same time, if they are connected in parallel, instead of in series. If they are in series, so that the undivided current has to go through both, the 16 c. p. lamp will not glow at all, if the converter is well built, unless one of the small lamps is burning on the secondary circuit; if the secondary current be short circuited for a very few seconds, by joining its terminals (resting a knife-blade upon them), the 16 c. p. lamp will glow brightly. The converter may be permanently introduced into the house circuit, if desired, as very little current will get through it, when none of the little lamps are burning; but it is probably better to switch it off from the house circuit' when no observations are being made.

A 1 c. p. Edison lamp consumes from 0.90 to 1.40 amperes of current. When this is glowing, if its voltage be 5, which is one-tenth of the E. M. F. of the house current, the current in the particular wires of the house circuit, which feed the little converter, will be only one-tenth as great as that flowing through the little lamp, provided that there are no losses in the converter. Mr. Richardson estimates the efficiency of the converter at 85 or 90 per cent. Hence a little rough figuring shows that the glowing of a 1 c. p. lamp causes a current of about one-eighth of an ampere to flow through the house wires. It is doubtful whether the house meter would be moved by so small a current. A house lamp usually consumes something over an ampere; so the use of a 1 c. p. lamp would cost about one-tenth as much as that of a house lamp, if the meter were sufficiently delicate to register the small current accurately.

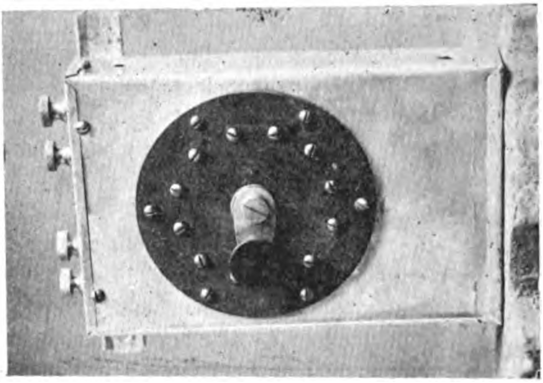

FIGURE 1.

Mr. Richardson arranged the converter which he built, so that it would give a current of the voltage of any particular lamp. The switch by which this is accomplished is shown on the face of the converter, in Fig. 1. The coils of the converter are enclosed in a stout tin box about the size of an oyster can, only the binding-posts and voltage switch being exposed. The top of the box, in which the posts are set, is a piece of vulcanized fibre.

The circular piece of vulcanized fibre on the face of the box holds the studs on which the switch rests. The studs are merely short round-headed brass screws, screwed into the insulating material. The arrangement of the wires connected with the switch is shown in Fig. 2. By the proportion given above we compute that for 4 volts the secondary coil should consist of 96 turns of wire, and for 5 volts, of 120 turns. One end of the secondary is attached to the binding post B. B′ is the other post which is connected by a wire with T, the turning point of the switch. When the switch is turned so as to rest upon the stud 4, the E. M. F. of the secondary current is 4 volts; studs 5 and 6 give potentials of 5 and 6 volts respectively, when the switch rests on them. The secondary wire from B makes 96 turns before it reaches the point where it is joined to 4. This connection is made by scraping off the cotton covering of the wire at X, and soldering on a short wire, the other end of which is fastened at 4. Between B and Y are 120 turns, and between B and Z are 144 turns. The connections of Y and Z with 5 and 6 are made in the same manner as at X.

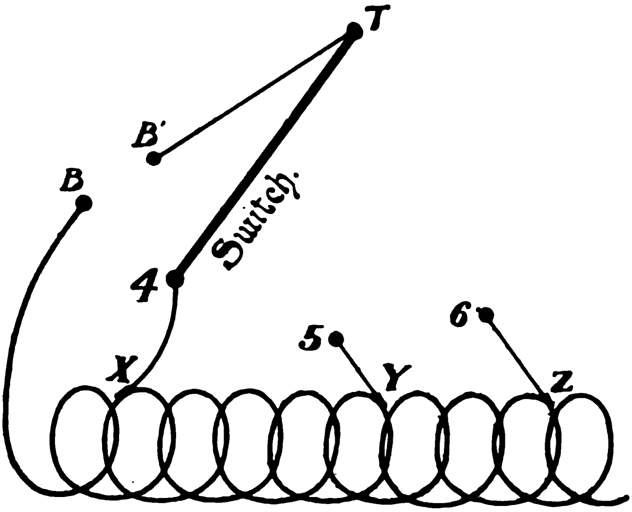

FIG. 2.

The switch may be utilized for varying the brilliancy of the light. If the voltage run from 4 to 6, it is a good plan to have every quarter volt between 4 and 6 represented by a stud, since a change of one-fourth of a volt makes quite a difference in the light. The number of turns for these intermediate voltages are readily computed. Where delicate regulation is required, as in the case of a micrometer lamp, a small coil, giving variable resistance by means of a switch, may be attached to the lamp itself, or to the telescope, within easy reach of the observer.

The Edison lamps may be obtained with colored glass if desired. Green, blue, purple or amber lamps cost $1.10; ruby lamps cost $1.20; all of these have pear-shaped bulbs; the ones which I have examined measure one inch in length by half an inch transversely. Lamps with much smaller cylindrical or spherical bulbs cost twice as much. Lamps of 2 c. p. have a voltage ranging from 4 to 7 volts, and consume from 1 to 1.50 amperes. Those of ½ c. p. consume from 0.80 to 1.35 amperes of a current having an E. M. F. of from 3 to 5 volts. With each lamp is furnished a ticket giving its voltage and amperage.

In conclusion we may call to mind the advantages of using a little transformer; four may be enumerated: The labor of taking care of a battery is obviated; any desired number of lamps may be used at once, as in a house; the light is steady; the cost of maintenance is very small.

Mr. Richardson has consented to build a transformer suitable for all the lights used about an equatorial; it will be at the World's Fair, with Mr. Saegmuller's exhibits of astronomical instruments.

CHAMBERLIN Observatory, University Park, Colo.

ON THE ORBIT OF ζ SAGITTARII.*

T. J. J. SEE.

In the *Monthly Notices* for 1886 (vol. xlvi, p. 444) Mr. Gore has given a first approximation to the elements of the orbit of ζ Sagittarii. This star has since been measured four times by Mr. Burnham at Mt. Hamilton, as well as by Leavenworth and Hall; and the additional data thus available seem to warrant the belief that a new determination of the orbit should give a much nearer approximation to the truth. Accordingly Mr. Burnham has selected all the measures which appear to be of any value and has drawn the accompanying apparent ellipse, from which the elements of the real orbit have been derived. It will, of course, be understood that this orbit is provisional, but it seems to be as good as we may hope to obtain from the data now available. Nor is it advisable to attempt anything like a definite

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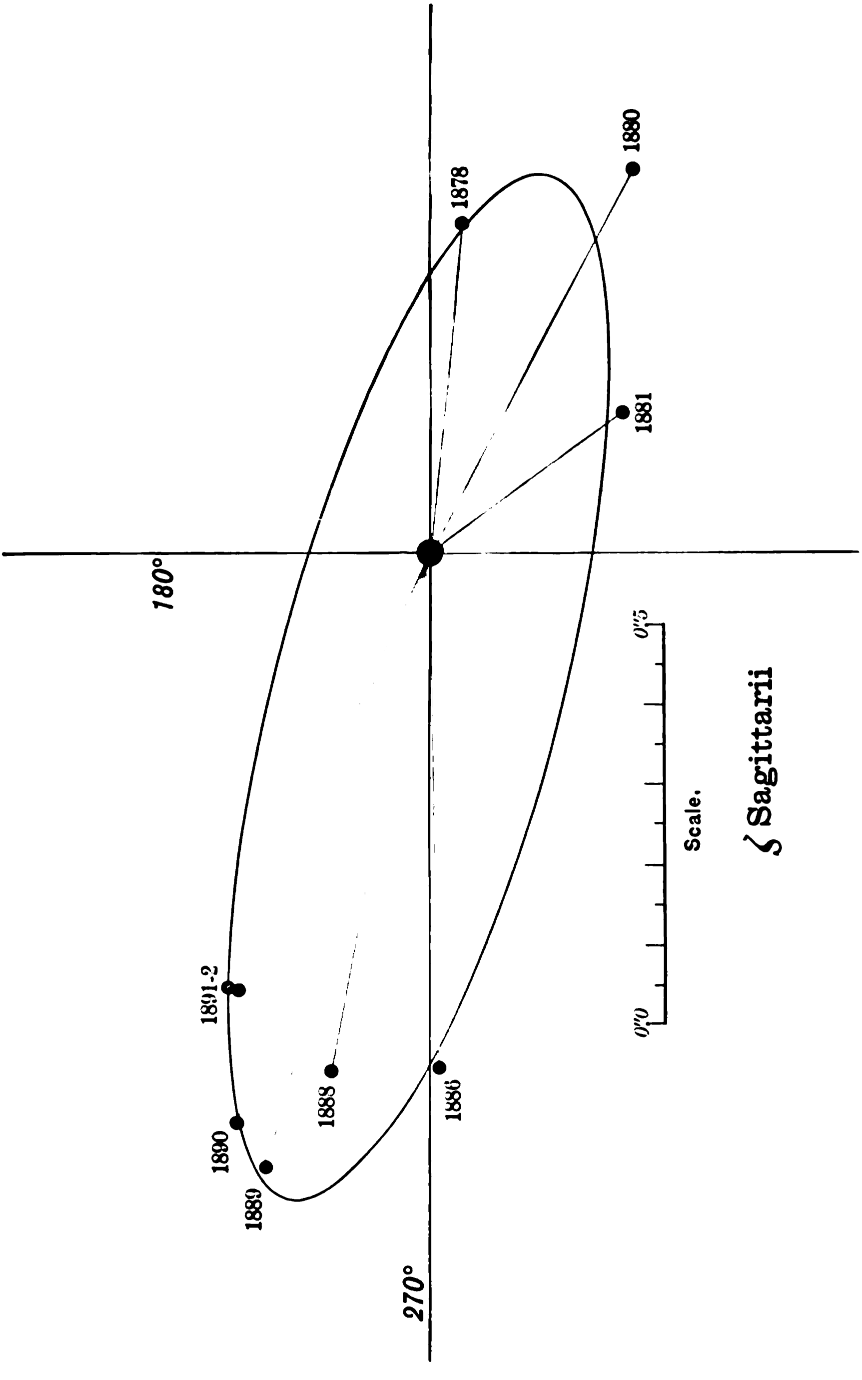
* Communicated by the author.

PLATE XXVIII.



determination, or an application of the method of least squares until the number of observations is very greatly increased. The apparent orbit seems to represent the observations very satisfactorily, and accordingly the real orbit is deduced directly from the apparent ellipse as shown in the figure.

Mr. J. W. Froley, a graduate student in astronomy of the University of Chicago, has, at my suggestion, determined the real elements by the graphical method of Klinkerfues. He finds the elements of the true ellipse to be as follows:

$$\left.\begin{array}{l} T = 1878.62 \\ e = 0.30 \\ i = 73^\circ.95 \\ \Omega = 75\ .35 \\ \lambda = 327''.35 \\ a = 0''.6800 \\ P = 17.715 \text{ years} \\ n = -20^\circ.321. \end{array}\right\} \text{Elements of } \zeta \text{ Sagittarii.}$$

It will be seen that the eccentricity is a good deal larger than that given by Mr. Gore (0.1698), and in this respect the present orbit conforms to the general rule among double stars. Mr. Burnham's apparent ellipse is based upon the following selected measures:

OBSERVATIONS OF ζ SAGITTARII.

t	ϑ	ρ	No. Nights	Observer.
1878.70	84°.2	0″.42	1	β
1880.62	62 .1	0 .55	2	β
1881.61	36 .1	0 .31	2	β
1886.62	271 .3	0 .65	4	Hl.
1888.66	259 .3	0 .67	7	Lv. & β
1889.41	255 .1	0 .81	5	β
1890.49	251 .1	0 .76	3	β
1891.53	246 .5	0 .61	3	β
1892 39	245 .1	0 .60	3	β

The elements given above represent these observations very well. The following are the computed and observed places:

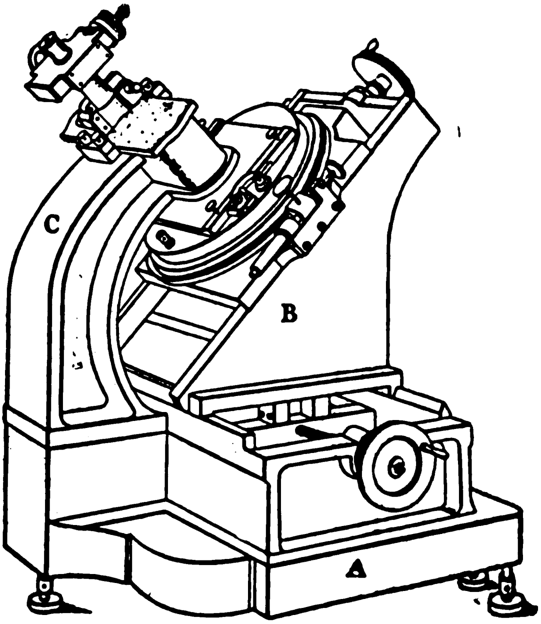
ϑ_c	ϑ_c	$\vartheta_o - \vartheta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$
84°.2	84°.2	± 0°.0	0″.42	0″.418	+ 0″.002
62 .1	63 .4	− 1 .3	0 .55	0 .456	+ 0 .094
36 .1	37 .3	− 1 .2	0 .31	0 .290	+ 0 .020
271 .3	269 .6	+ 1 .7	0 .65	0 .657	+ 0 .007
259 .3	260 .8	− 0 .5	0 .67	0 .829	− 0 .160
255 .1	258 .1	− 3 .0	0 .81	0 .844	− 0 .034
251 .1	254 .3	− 3 .2	0 .76	0 .814	− 0 .054
246 .5	249 .9	− 3 .4	0 .61	0 .724	− 0 .114
245 .1	245 .1	± 0 .0	0 .60	0 .600	± 0 .000

This star will for the next few years be rather difficult to observe, but the great interest attaching to so promising a system ought to induce observers with large telescopes to give it careful attention. If it can be followed for a few years its orbit can be determined with the desired precision.

The UNIVERSITY of Chicago, 1893, May 16th.

A NEW APPARATUS FOR MEASURING PHOTOGRAPHIC PLATES.*

The new apparatus, constructed by M. Gautier, was installed in May, 1892. This apparatus is a casting; it consists of a fixed horizontal piece *A*, furnished with two rails, on which slides an inclined plane at an angle of 45°, moved by a screw 0.18^{m} in length with a pitch of 0.005^{m}. On this inclined plane another screw of the same length as the first moves a cast frame, upon which is a movable circle, without graduations, carrying the fixed frame destined to receive the plates to be measured.



Each plate, when in place, is susceptible of three motions; a rotation, serving to orient in any required direction and two rectilinear motions, one of which is effected on the horizontal piece *A*, the other on the inclined plane *B*.

Each of the pieces *A* and *B* is furnished with a scale divided to millimetres, serving to count the turns of the screw. The curved piece *C*, which is cast with *A* terminates in a large groove designed to receive the microscope and micrometer box.

The heads of the two micrometer screws are divided to 100 parts. The value of one turn of each differs little from 1′; the tenths of divisions may be estimated, so that the readings may be made to about 0.06″

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* From "Rapport annuel sur l'état de l' Observatoire de Paris, pour l'année 1892."

Astro-Physics.

THE SPECTRA AND MOTIONS OF STARS.[*]

W. H. S. MONCK.

In the preliminary volume to the Draper Catalogue (published after the catalogue itself), there is a table of stars whose spectra were re-examined with longer exposure in consequence of Vogel or Konkoly having arrived at a different conclusion from Pickering as to the character of the spectrum. The result is upwards of 200 corrections. Few of these affect the brighter stars, and there is consequently no appreciable error in my analysis of the Catalogue of Auwers. It was otherwise, however, with the Pulkova Catalogue and I found some other errors in my analysis of it. I therefore decided to send you a revised version omitting the stars common to both catologues, so that the results of the two investigations should be independent. The general effect of the changes are as follows: Several stars classed as A pass with longer exposure into class B, but they are all slow-moving stars, so that the motionless character of stars with spectrum B remains unaffected. Several stars classed as E pass into the class G as do also some of those classed as F. The result seems to be that stars with spectrum G undoubtedly belong to the Capellan, not the Arcturian type, and I shall treat them accordingly in the present article. Stars with spectrum M are also increased in number and, to a certain extent, in proper motion by longer exposure.

With this preface I give my revised results of the Pulkova Catalogue under the three heads of Sirian, Capellan and Arcturian stars. The superiority of the Capellan over the Arcturian stars as regards proper motion, and probably as regards nearness seems to me as well established as that of Solar stars over Sirians.

	No. of Stars.	Standard Motion over 1″.00	Standard Motion over 0″.50
Sirian	787	50	149
Capellan	246	93	139
Acturian	460	73	162
Type M	49	3	15

Of the stars classed as Sirian 42 have spectra of the class B. None of these has a standard motion (in N. P. D.) of as much as half a second annually.

The Cincinnati Catalogue contains stars with large proper motion only. I did not think it necessary to ascertain their stand-

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[*] Communicated by the author

ard motion, which would generally be very considerable but thought it desirable to examine the spectra of the stars included in this Catalogue but not included either in Auwers' Catalogue or that of Pulkova. The result was as follows, Capellan Stars 85, Arcturian 62, Sirian 44. Of the latter *one* star (ξ Ophiuchi) has the spectrum B. I did not find any star with the spectrum M which had not occurred in either of the preceding catalogues.

That binary stars whose orbits can be computed are comparatively near to us will, I think, be generally conceded. I lately received from Dr. See a copy of his recent work on the subject which contains a larger number of orbits than any preceding catalogue. Comparing his list with the Draper Catalogue I identified 32 Capellan stars, 14 Sirians, 8 Arcturians and one with the spectrum M. The Arcturian binaries I may remark are extremely few. The spectra of four of the eight are marked doubtful in the Draper Catalogue and in two other cases (the well known stars 61 Cygni and γ Leonis) there seems to be a similar doubt as to the orbit.

What are we to infer from this state of facts as to the structure of the universe? That the solar stars (and I think I may now add the Capellan stars in particular) predominate among our nearer neighbors appears certain. But the opinion seems to be gaining ground that beyond the solar cluster the Sirian type predominates and that in particular, the Galaxy is mainly an aggregation of Sirian stars. The evidence available at present does not, I think, warrant any such inference. If indeed it were shown that the motions of the stars in the Galaxy, or of the Sirian stars generally, gave a different apex for the Sun's way from that derived from the motions of the solar and non-galactic stars (which have hitherto been chiefly employed for the purpose) we might reasonably conclude that we were dealing with two distinct star systems; while on the other hand, if we got the same apex (within the limits of probable error) from the two computations we might perhaps deduce the contrary conclusion. But the relative paucity of solar stars in any direction where faint stars are numerous admits of a very different explanation. A solar star is probably, on the average, a magnitude and a half fainter than a Sirian star of the same mass placed at the same distance from the eye. Let the Sirian star, for instance, be of magnitude 5.5. Its spectrum will probably be recorded in the *Draper Catalogue* which contains a majority of the Northern stars up to that magnitude. But the corresponding solar star will be of the 7th magnitude, and stars as faint as this very rarely occur in the Catalogue. With greater power or longer exposure, these solar stars would appear, but unless we are able to look *through* the stars in this direction a number of additional Sirian stars will crop up at the same time still maintaining their numerical superiority. In short the solar stars whose spectra we are photographing are comprised within a sphere having only about half the radius of that containing the Sirians which appear on the same plate.

Results derived from Catalogues of proper motion are little more reliable. Suppose that among the known stars having a proper motion of between 0″.05 and 0″.10 annually, the Sirians predominate, who shall tell us how many faint telescopic solar stars are moving with this velocity? No inference can be drawn until our Catalogues are presumably complete; otherwise the greater brightness of the Sirian stars will give them an apparent supremacy which may prove wholly deceptive. As far as our certain knowledge reaches, solar stars preponderate. Whether beyond that limit Sirian stars assume the same relative superiority, is a problem of the future which we are not at present in a position to solve.

THE DISTRIBUTION OF THE STARS.[*]

MISS A. M. CLERKE.

The fundamental difficulty of stellar astronomy is that of rightly inferring the real from the projected places of the stars. Prolonged study is needed to show that they are not scattered at random over the sky. They shine down upon us as if flung loosely over the surface of a sphere, and indeed owe their name of "fixed" stars to the crude early notion of their being rivetted —*infixæ*—to the "palace-roof" they very effectually serve to adorn. Yet in reality this starry vault integrates, so to speak, immeasurable abysses of star-strewn space. There, as elsewhere, "things are not what they seem," and we are confronted with the inevitable question as to the relation between the thing that is and the thing that seems. From the aspect of the Milky Way came the first suggestion of an answer. The thought could not but present itself to intelligent inquirers that the dimly-shining girdle of the sphere might exercise a governing influence over its contents. Varied investigations of this obvious possibility were

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[*] *Knowledge*, April, 1893.

accordingly carried out, and the fact was established of a general increase of stellar density, gaining intensity with descent in magnitude, towards the galactic plane. The combination into a system was thus rendered probable of the sprinkled stars of the constellations and the streaming stars of the nebulous zone running through them; but no hint could be gathered as to the nature of the combination. Only the bare existence of some principle of arrangement was perceived by unsatisfactory glimpses.

Until lately the only practically available means of searching out the plan of stellar structure was by instituting comparisons between the numbers and the magnitudes of the stars. Average brightness, it was reasonably supposed, gave a measure of average relative distance, and from distance relative abundance per unit of space could be inferred by simply counting the successive photometric ranks. But the value of this method has been impaired by an advance of knowledge in two directions. In the first place it became evident, on a wider acquaintance with stellar proper motions, that their assorted amounts afforded a much surer test of distance than could be derived from the consideration of magnitude alone. Next, it came to be recognized that the intrinsic brilliancy of stars is very different for different spectral types, so that stars of the Vega type must be nearly three times more remote than stars like Capella or the Sun, equally massive, and possessing the same visual brilliancy. Diversity of stellar type implies then, diversity in laws of distribution—diversity, not only of the photometrical, but also of the physical kind, and hence constituting an essential feature of sidereal organization. The preponderance of Sirian stars in the Milky Way, simultaneously ascertained during the progress of Professor Pickering's spectrographic survey and of Dr. Gill's photographic Durchmusterung, appears to be a combined result. In part, it must depend, as pointed out by Mr. Monck, upon the crowding in of Sirian stars lying far beyond the limiting distance of the included solar stars; but there is reason to believe that it is also in part produced by a genuine relationship. What is certain is that it fits in with much that was already known, and provides a fresh platform for further inquiry.

It was in great measure through the labours of Professor J. C. Kapteyn, of Groningen, in measuring and reducing the Cape Durchmusterung plates, that the systematic difference in question was detected; and their conclusion has allowed him leisure to follow up the clue thus placed in his hands. He has done so by a research into the distribution of the stars, with special reference to their spectral types, communicated to the Amsterdam Academy of Sciences in two important papers, read April 29th, 1892, and January 28th, 1893, respectively. The first, indeed, gave only preliminary inferences, but they were ratified and extended in the second by the discussion of a greatly enlarged stock of data. These related to 2357 stars, of which 1189 are classed in the Draper Catalogue of Stellar Spectra as of the first, 1106 as of the second, and 62 as of the third type. The proper motions of 476 of them were taken from the list prepared by Herr Stumpe for his determination of the solar translation; those of the rest from the Bradley-Auwers catalogue. The treatment of this material was on the principle that stars are, on a fairly wide average, distant from us in the inverse ratio of their apparent movements. So far as concerns the perspective element contained in them, this is of course strictly true, allowance being made for differences of angular position with regard to the apex of the Sun's way. That is to say, the line traversed in a given time by the Sun, if seen *square* from any star, would be of a length proportionate to that star's remoteness; and the transferred displacement of the star, as viewed from the Sun, would be equal and opposite to the proper displacement of the Sun as viewed from the star. Thus, assuming the direction of the solar translation known, and the "peculiar" movements of the stars to be so irregular as to give a zero effect when numerously thrown together, a secure measure is afforded of comparative stellar distance. Professor Kapteyn accordingly resolved his proper motions into two components, one directed along a great circle passing through an apex in R. A. 276°, Dec. + 34°, the other at right angles to it. The first, reduced to a position 90° from the apex, was treated as of wholly perspective origin; the second could not but be wholly original. And it was reassuring to find that their values (abstraction being made of a few exceptionally swift objects) varied in groups of stars arranged according to proper motion, pretty nearly in the same proportion. Either component, then, of stellar motion—the parallactic, or the peculiar—appears to supply a valuable criterion of stellar distance.

The initial difficulty connected with space-sounding operations being thus removed, a number of interesting conclusions lay, comparatively speaking, close at hand. Some of these had been anticipated by Mr. Monck, and their independent deduction, through a far more elaborate investigation, shows them to be deserving of no small credit. To begin with, the remarkable circumstance seems fully established that stars with well-accentuated proper motions show predominantly spectra of the solar description.* Nor can we hesitate to agree that these objects owe their mobile character to their relative vicinity. They constitute, accordingly, a group which surrounds and includes the Sun. It is most likely roughly spherical in shape, and is so strongly condensed interiorly that a volume of space near its centre contains 98 times as many stars as an equal volume near its circumference. The maximum compression appears to be round a point† lying away from the Sun, towards the northwestern section of Andromeda, supposed by Professor Kapteyn to coincide with the centre of the Milky Way. But this identity is highly questionable. It depends —since the centre found for the cluster has a southern galactic latitude of about 20°—upon the truth of Sir John Herschel's and Struve's respective inferences of a position for the Sun, eccentric as regards the round of the Galaxy, and to the north of its medial plane. The brilliancy of the Milky Way, however, in the southern hemisphere affords in reality not the slightest presumption of nearness;‡ and Gould was unable, from a much more complete inquiry than Struve's could possibly be, to assign to the Sun either north or south galactic latitude. His situation, for anything that can be proved to the contrary, may be perfectly symmetrical within the great cosmical annulus. It cannot then be admitted, at least on the present showing, that the latter is concentric with the newly constituted solar star-group, which it may be remarked, has little or nothing in common with "Gould's cluster." This is projected in the form of a belt, and is largely made up of Sirian stars with slight or inappreciable proper motions; while Professor Kapteyn's collection shows no preference for the galactic, or any other plane, and includes only a slight sprinkling of "white stars," such as Vega, Sirius, Altair and Regulus, admitted because of the vicinity implied by their motions.

Beyond a certain limit of distance (estimated by proper motion), both Sirian and solar stars exhibit marked condensation towards the plane of the Milky Way. The former, indeed, much more than the latter; yet even solar stars, when remote enough to be sensibly stationary,§ obey the law of galactic attraction to an equal extent with the whole body of stars down to the ninth

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* See Ranynard, *Knowledge*, Vol. XIV, p. 50; *Old and New Astronomy*, p. 798.

† The co-ordinates of which are R. A., $0^h\ 0^m$, Decl. + 42°.

‡ Sutton, *Knowledge*, Vol. XIV, page 42.

§ With proper motion, that is to say, smaller than 0''.04.

magnitude. The distribution, accordingly, of second type stars is apparently regulated by two distinct principles; and the first, that of globular aggregation about the Sun, acts altogether independently of the second, that of galactic thronging. But how the sphere and the stratum resulting severally from the two kinds of influence are related, whether they are contiguous or widely separated, we have no means of determining.

Stars of the first type are more equably distributed. They are at least exempt from the tendency of their correlatives to concentration in the neighborhood of the Sun. On the other hand, they are drawn more strongly towards the Milky Way. They accumulate mainly into a disc, or possibly into a series of rings. The proportion of their numbers to those of second type objects grows rapidly with increase of distance. Outside a sphere, of which the radius corresponds to an annual proper motion of 0″.07, they are in a minority smaller and smaller as its centre is approached; outside of that sphere they claim about a two-fold numerical superiority. But is the superiority real or fictitious? We seem obliged to adopt the lattealternative. The disparity can, at any rate, be amply accounted fory the systematic difference in real brightness between the two great stellar orders.

Professor Kapteyn holds that there is no satisfactory evidence of their differing systematically in real swiftness. He has investigated the matter with a negative upshot. At equal distances, he finds Sirian and solar stars to be pretty equally displaced. The balance, that is to say, does not so far incline decisively either way. But at equal distances Sirian stars appear brighter by more than two magnitudes than solar star of similar mass. To send us the same quantity of light, they must then be 2.7 times more remote. Hence, obviously, an indiscriminate collection of stars exceeding a given magnitude represents the contents of a far larger volume of space as regards the first than as regards the second stellar order.* If the latter be included in a sphere of mean radius = 1, the former must be diffused through a sphere of radius = 2.7. The true proportion of their numbers, as compared with solar stars, would accordingly be increased in such a collection not far from twenty times! And the chief part of these adventitious stars, if they may be called so, would naturally fall into the ranks of immobile objects. To their presence, then, the excess of the first type spectra among the Bradley-Draper stars with evanescent proper motions may safely be attributed.

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* This mode of reasoning has been anticipated by Mr. Monck.

The leading results of Professor Kapteyn's able and exhaustive discussion may be recapitulated in the two following propositions:—

1. Stars with appreciable proper motions belong mainly to the solar spectral class, and gather round a point adjacent to the Sun, in total disregard to the position of the Milky Way.

2. Stars sensibly fixed, Sirian and solar alike, although not to the same extent, collect towards the galactic plane. Both types can hence be inferred to obey the same organic laws, and to be united into a coherent whole.

An unexpected peculiarity of distribution, indicated by this investigation, if not convincingly proved by it, is that stars of determinate magnitude of either type are on the whole more remote when situated in or near the Milky Way. It can only be explained as due to a greater prevalence of larger or more luminous bodies in that region than in other parts of the sky.

The general shape of the stellar universe is compared by Professor Kapteyn to that of the Andromeda nebula, as depicted in Mr. Roberts's photographs. The globular nucleus represents the solar cluster, the far-spreading rings or whorls the compressed layers of stars enclosed by the ring of the remote Galaxy.

[Professor Kapteyn's conclusion that Sirian stars appear brighter by more than two magnitudes than solar stars of similar mass is very interesting in connection with the evidence we already possess as to the relative density of Sirian and solar binary stars. The tables given on pages 796-7 of "The Old and New Astronomy" give 0.3094 as the mean density of the binary stars of known period whose spectrum is of the solar type, and 0.021 as the mean density of the binaries of known period whose spectrum is of the Sirian type—that is, solar binaries are on the average about fifteen times as dense as Sirian binaries.

So that, if Sirian stars and solar stars have photospheres of equal brightness, the Sirian stars will have on the average a diameter nearly two and a half (2.466) times as great as the diameter of solar stars of the same mass, and they would appear equally bright to us if situated at 2.466 times the distance of similar solar stars. In other words, the evidence derived from binary stars shows that Sirian stars appear to us nearly two magnitudes brighter than solar stars of similar mass.

Professor Kapteyn's general result seems to me to be involved in his assumption that proper motions are to be taken as the criterion of distance. This seems to me to involve the assumption that all types of stars are moving with the same average velocity, an assumption which is not self-evident, but which seems, on the contrary, improbable in view of what we know as to certain types of stars being associated in clusters. Such clusters evidently form systems, and the individual stars cannot therefore have large proper motions relatively to one another, for such motions could not be controlled by the mutual gravity of the stars forming the system.

A solar cluster of swift-moving stars, such as Professor Kapteyn supposes, could not form a permanent system. The vast velocity which we know that our Sun and other stars having large proper motions are endowed with would carry them away from the centre of gravity of such a system, if it was composed only of the swift-moving bright stars we see. Their swift motions cannot be controlled by one or more dark stars of enormous mass, for the places of such dark attracting masses would be indicated by the symmetry of the motion of the bright bodies about them; and it is evident that such a solar cluster could not be held together by the attraction of rings of matter outside it.—A. C. RANYARD].

THE TEMPORARY STAR IN AURIGA.*

A. L. CORTIE.

The year 1892 will be famous in the annals of astronomy for two remarkable discoveries; the one, that of the fifth satellite of Jupiter, made by a trained astronomer, Mr. E. E. Barnard, on the night of September 9th, by means of the giant thirty-six inch equatorial of the Lick Observatory; the other, the subject of the present paper, made in the earlier part of the year by the Rev. Dr. Thomas D. Anderson of Edinburgh with such simple appliances as a small hand-telescope and a star-atlas. Whilst examining the constellation of Auriga in the last days of January, this gentleman observed a star of the fifth magnitude, or order of brightness, which at first he identified with the well-known star numbered 26 in maps and catalogues. Further scrutiny, however, and comparison with his star-atlas, revealed to him the probable existence of one of that rare class of celestial bodies, which attain but a temporary splendor, and then are seen no more. The information was therefore diffidently communicated to the Royal Astronomer for Scotland, Dr. R. Copeland, on the

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* Communicated by the author.

morning of February 1st, by means of an anonymous postcard. The same night the orange-tinted stranger was sought for and easily found at Edinburgh, while at Greenwich the Astronomer Royal secured photographs of the star and of the surrounding neighborhood. The next day the telegraph wire had announced to the leading astronomers of the world, that a new star was to be seen in the Milky Way situated about two degrees to the south of χ Aurigæ, and preceding No. 26 of the same group of stars. The nearest bright star to the place of the Nova is β Tauri.

But an interesting fact was the result of subsequent examinations, suggested by Anderson's discovery, of star plates of this region of the heavens which had been taken in the preceding December by Professor Pickering at the Harvard College Observatory, and Dr. Max Wolf at Heidelberg. For while the star was absent from the photographs taken by the latter astronomer on December 8th, which showed stars of even the eleventh degree of brightness, it had two days later impressed its image on the plates of the American observer, as a star equalling in lustre those of the fifth magnitude. Hence it appears that in this interval of time it had risen through more than six degrees of brilliancy, thereby indicating a multiplication of its light and heat-giving powers in the proportion of one to two hundred and fifty. So distant too is it, that now that the Earth has completed since its first discovery more than two-thirds of its annual course round the Sun, the observations of Burnham and Barnard at the Lick Observatory have not succeded in bringing to light the slightest parallactic displacement of the object on the celestial sphere. Hence it is impossible to tell when the actual conflagration in the heavens took place, which was first recorded on the Earth on the night of December 10, 1891. It is no exaggeration to suppose that a star with a radiative power a hundred times greater than that of our Sun, commenced to send its message to us at the rate of one hundred and eighty-six thousand miles a second at least two centuries ago.

The discovery of temporary stars has hitherto been of very rare occurrence, the average being one for each of the last nineteen centuries. The first instance of which we have any record is that of the star discovered by Hipparchus, probably about the year B. C. 134. In this case we know the bare fact, and the interesting statement of Pliny that it was this discovery which induced the Greek astronomer to draw up his star-catalogue, the very first that has come down to us. Then there was Tycho

Brahe's famous star which blazed out in Cassiopeia in the year A. D. 1572, and was to be seen for a year and five months. Of this star it is recorded that its color changed from white through yellow to red, and then to white again, which furnishes us with some clue to a probable fluctuation in and recuperation of its light. In A. D. 1604 another Venus-like star, observable for a year, was discovered by the famous Kepler, while the same century furnished yet another example in Anthelm's Nova of A. D. 1670, which was to be seen for two years, the brilliancy fluctuating in a remarkable manner. The present century has been marked, including Nova Aurigæ, by five such apparitions; namely, in 1848, when a star was discovered by Dr. Hind in Ophiuchus; in 1866 when a star in the Northern Crown blazed up suddenly from the ninth magnitude to the fourth magnitude, and after again increasing its lustre six-fold in about three hours, finally became one of the class known as variable stars; in 1876 in the constellation Cygnus, a star of an orange-red tint which attained a lustre equal to that of a third magnitude star, and which according to an observation made by Burnham at Lick Observatory in the latter part of 1891, is a small star of 13.5 magnitude, and "at times seemed to resemble an exceedingly minute nebula,"* and finally in 1885 when a star just visible to the naked eye appeared in the very heart of the wonderful Andromeda nebula, with which, as observations seemed to show, it was physically and not merely optically connected. Of these recent stars, four have been subjected to spectroscopic analysis, and we shall have occasion to notice in the sequel some of the indications which they gave, but the Nova Aurigæ is the first star the light of which has been analyzed and permanently recorded for future study on the photographic plate. For the present we note with regard to these temporary or new stars the following common characteristics, suddenness of outburst, great rapidity in the attainment of their maximum of splendor, then decline, in some cases rapid, in others more leisurely, and finally in several cases a recrudescence of brilliancy.

It was not long after the news of the arrival of Nova Aurigæ had been bruited abroad, before its light was confronted by eye and by photometer, by photographic plate and by micrometer, and by that powerful engine of modern research the tele-spectrograph, or combination of telescope, spectroscope and photographic plate. It would be impossible within the limits of a single article to enter into all the niceties of, or indeed to give

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* *Monthly Notices, R. A. S.*, vol. 52, No. 6, p. 457, April 1892.

anything like a complete account of all the observations made on this interesting star. We must therefore be content to summarize the chief results of these observations, and in doing so we propose to discuss the history of the star in two sections, the first dealing with such results as were secured between its first appearance and its decline during the months of March and April, 1892, and the second with the observations made upon the star during its recuperation of brilliancy in the months of August and September.

With regard to the magnitude of the star we must, at the outset, distinguish between its magnitude as determined by eye or by the photometer, and that resulting from its images as impressed upon a photographic plate. For should the star be rich in rays to which the photographic plate is sensitive, but which do not affect the eye, the resulting magnitudes will be greater by the photographic than by the eye method of estimation. The magnitudes of the star during its first appearance have been studied among others by Pickering, Christie, Pritchard, Knott, Roberts, Stone, Burnham, Whitney, Gore, Baxendell, Lohse, Newall and Copeland, and the result of a comparison of such observations is that the photographic exceeds the visual magnitude of the star.* The earliest observations were those secured on Pickering's plates at Harvard College Observatory between the dates December 10th and January 20th, 1891. From these it appears that "the magnitude of the star on December 10th was 5.4," and that "the brightness increased rapidly until December 18th, attaining its maximum about December 20th, when its magnitude was 4.4. It then began to decrease slowly with slight fluctuations until January 20th, when it was somewhat below the fifth magnitude."† We have already noticed that it did not appear among the eleventh magnitude stars on Max Wolf's plate on December 8, 1891. Dr. Copeland too has "examined a large number of star maps and catalogues, ancient and modern, without finding any previous record of the new star."‡ Dr. Anderson is almost certain that he observed the star on January 24th, and twice in the following week, and that during the days preceding

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* *Monthly Notices R. A. S.* vol. 52, No. 5, pp. 357, 366, 367, 371, No. 6, pp. 430, 432, 433, No. 7, pp. 508, 509: *Astronomy and Astro Physics*, March, April, May, June, August, 1892; *Journal B. A. A.* March, April. Curves showing the fluctuations of the magnitude of the star are to be found in *L'Astronomie* for June, 1892, the *Journal B. A. A.*, for April, 1892, drawn up by the Rev. T. E. Espin, and in Dr. Copeland's paper reprinted in *Astronomy and Astro-Physics* for August, 1892.

† *The Observatory*, No. 187, April, 1892, p. 197.

‡ *Astronomy and Astro-Physics*, No. 107, August, 1892, p. 593.

the despatch of his postcard, it was of about the fifth magnitude. But since February 1st a series of systematic observations of the magnitude of the star has been secured. According to the Astronomer Royal it attained its maximum of brilliancy on the night of February 3rd, being then 3.5 as estimated from its photographic image, while Pritchard, at Oxford University Observatory, gives 4.82 by the photometric method, and Stone, of the Radcliffe Observatory, 4.4 by eye estimation, all three observers agreeing however as to the date of the maximum. This, then, was a second maximum. A steady loss of light then ensued until about March 16th, between which date and the 19th it again took a slight rise. Again a fall is recorded in the light-curve of the star, with a halting-point at magnitude six until March 8th, when it commenced to fall steadily and rapidly. By March 18th it had diminished to the ninth magnitude, on the 25th it was at the tenth, on the 28th it had fallen to the twelfth magnitude, and by the beginning of April it was a faint thirteenth magnitude star. It was clearly seen in the Lick telescope on April 24, "when it was of the sixteenth magnitude or fainter."* We have therefore in this first appearance a sudden outburst, a rapid rise to brilliancy, a fall, another rise to maximum lustre, again a fall, a third rise though less brilliant than its predecessors, and finally a rapid and persistent fall to extreme faintness. Moreover the star is rich in violet rays as shown by the excess of the photographic over the eye estimations of brilliancy.

The revelations of the spectroscope next claim our attention. On the very night of the announcement of its discovery, February 1st, Copeland, at Edinburgh, was able by means of a small spectroscope to detect the likeness of its spectrum to that of the Nova of 1866. "The C line was intensely bright, a yellow line about D fairly visible, four bright lines or bands were conspicuous in the green, and lastly a bright line in the violet (probably $H\gamma$) was easily seen."† Glowing hydrogen was at any rate present in vast quantities as a constituent of the new star, while the lines in the green seemed to indicate a generic likeness between the Nova and that which appeared in Cygnus in 1876. On the night of February 2nd, Dr. and Mrs. Huggins commenced their study of the spectrum of the star, its spectrum was also photographed on February 3rd by Professor Lockyer at South Kensington and by Father Sidgreaves at Stonyhurst, and before a few days had elapsed from the announcement of the discovery its light had

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* *Astronomy and Astro-Physics*, No. 108, October, 1892, p. 715.

† *The Observatory*, No. 186, March, 1892, p. 136.

been analyzed either by the visual or spectrographic methods by many observers. Thus among others we have observations from Pickering at Harvard, Young at Princeton, Vogel at Potsdam, Campbell and Crew at the Lick Observatory, Bélopolsky at Pulkova, Maunder at Greenwich, Becker at Dun Echt, Copeland at Edinburgh, Eugen von Gothard at Héreny, Konkoly at O-Gyalla, and Espin at the Wolsingham Observatory.* An early paper on the spectrum was that presented by Professor Lockyer to the Royal Society, and dated February 4th, in which he announced the probable appearance in the spectrum of Nova of the three lines characteristic of the spectrum of the nebulæ, namely, the hydrogen line at F, the line near wave-length 500 in the green, which was coincident in his spectroscope with the radiation from burning magnesium wire, while a third line was probably coincident with the nebular line 495. The carbon fluting at 517 was also represented. The hydrogen C line was present and of great brilliancy, a feeble line in the yellow was near the place of the sodium line D, and a photograph of the spectrum showed thirteen additional lines, among them being the hydrogen lines at G′, *h*, and H. Now, according to Professor Lockyer's researches into the constitution of meteorites, the spectrum of these bodies always shows first the hydrogen spectrum, then as the temperature is increased the spectrum of carbon, or one of its compounds, while at a still higher temperature the magnesium spectrum begins to appear. According to the "Meteoritic Hypothesis" of the same spectroscopist, the spectra of those nebulæ which consist of bright lines, can be matched by the spectrum of meteorites, for the line near 500 coincides with a low temperature magnesium fluting, and the hydrogen line F is certainly present. Temporary stars too according to this hypothesis give a spectrum which is identically that of the meteorites, and their origin is to be ascribed to encounters between the constituents of two meteor streams which, as Professor Lockyer suggestively expresses it, meet at a "level crossing." We have thus early in our summary of the spectroscopic observations called attention to Professor Lockyer's observations and theories as we shall have afterwards to compare them with the results of other observers, in our endeavour to find some solution for the riddle, and it is a great one, set us by the spectrum of the Nova of 1892. Luckily we have observations over every portion of the extent of its spectrum, which extended from the extreme red even below the C line

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* Published in the *Proceedings R. S.*, the *Monthly Notices R. A. S.*, *Astronomy and Astro-Physics*, *The Observatory*, *Nature*, *Astronomische Nachrichten*, etc.

according to observations of Professor Young, and of Dr. and Mrs. Huggins, to that limit in the ultra-violet where the light of celestial bodies ceases to overcome the absorptive effect of our atmosphere, as was shown by the photographs taken by the last-named observers. As is well known, the ordinary photographic plates are only sensitive either in the violet or in the blue; beyond F we have to depend for the most part on visual observations through the green, yellow, orange, and red portions of the spectrum. The plates used at Stonyhurst, however, were those which are rendered by the use of suitable dyes sensitive also to green light, and Father Sidgreaves' photographs extend from D in the yellow to H in the violet, thus admirably supplementing those of other observers.

The first fact then about the spectrum of Nova Aurigæ is that it was of great extent, and not confined to any particular colour or colours, unlike the spectrum of Nova Andromeda in 1885, which was, allowing for the difficulties of observation, mainly confined to the green. Moreover, throughout its whole extent the spectrum was full of lines, both bright lines and dark lines, and these again were contrasted with the background of a well marked continuous spectrum. To give some idea of the number of lines which the stars showed there were nearly sixty well marked and unmistakable bright and dark lines or bands in the Stonyhurst photographs, which under a powerful microscope after a week of study independently resolved by at least two observers into more than two-hundred lines, the spectrum being a most complicated one. The maps drawn by Dr. and Mrs. Huggins in those parts which are supplementary to the Stonyhurst photographs, furnish about forty other lines.* Dr. Becker too, at Dun Echt, measured seventy-one bright lines in the visible portion of the spectrum and a very extensive catalogue of lines has recently been published by Professor Campbell. So that our second fact with regard to the spectrum of Nova Aurigæ is that it was rich in bright and dark lines.

Many of these lines too, were of great breadth, notably, those of hydrogen, the F and G′ lines extending over several tenth-metres. These lines seemed to be also sharper on the side towards the violet end of the spectrum, and more diffuse on that turned towards the red end. They presented the appearance characteristic of the lines of the gas, when it is under great pressure and of great density. It has been objected that this immense broadening of the lines was possibly a photographic effect due partly to the

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* Proceedings of the Royal Society, vol. 51, p. 488.

necessarily long exposures, and partly to the scintillation of the star.* But a series of experiments undertaken for the express purpose of the solution of this question by Father Sidgreaves on γ Cassiopeiæ, and other stars, has proved that the effect in Nova is not photographic, but has a true physical cause to be looked for in the constitution of the star. In 1879 and succeeding years Dr. Huggins took a series of photographs on the ultra-violet spectrum of Sirius, Vega, and other bright white stars, and his plates showed besides the well known hydrogen series G′, *h*, H, of the violet, nine other lines of similar appearance and arranged in rythmical order. The detection of these lines in the stars led to laboratory experiments, and they were identified by Lockyer, Vogel, and Cornu, as all forming part of a harmonic series and due to hydrogen. The quite recent advances in the study of the solar atmosphere made by Hale at Chicago and Deslandres at Paris, by means of photography, have added these same lines, and five others in addition further removed still to the violet, to the hydrogen lines of the Sun. Now Dr. and Mrs. Huggins' photographs of the ultra-violet spectrum of Nova Aurigæ, show this same series of lines in the spectrum of the star. We cannot thence conclude that Nova Aurigæ was a star like Sirius or other stars of Secchi's Type I; for in addition to these lines, which we now know to be proper to the Sun also, the spectrum of Nova was, as we remarked before, full of lines from the extreme red to the extreme violet. Was the spectrum then like that of our Sun in its other details, and could it therefore be relegated with the Sun and other yellow stars as Aldebaran, Capella, Pollux and Arcturus to Secchi's Class II? But we have already seen that Professor Lockyer identified in the new star the nebular triplet in the green, the lines of hydrogen and a carbon fluting. The point then as to what gases or metallic vapors the lines were attributable needs careful consideration. And first, the weight of evidence is entirely against Professor Lockyer, with regard to the presence of the chief and characteristic nebular line and the carbon spectrum; though of course all observers are agreed that the hydrogen formed a marked constituent of the blaze of the new star. The absolute position of the chief nebular line near 500 has been determined with great exactitude by Professor Keeler with the magnificent apparatus at Lick Observatory. The number given by this observer is 5005.93.† The position of the very bright line near 500 in the Nova which was ascribed to the nebular spectrum by Profes-

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* The Observatory, No. 187, April, 1892, page 165.

† Proceedings of the Royal Society, vol. 49, p. 401.

sor Lockyer, was likewise independently determined by other observers. Dr. Huggins placed it at 5014, Professor Young at 5015, Father Sidgreaves at 5014, Professor Vogel at 5016, Herr Eugen von Gothard at 5019, Herr Konkoly at 5019.5 while the observations of Dr. Becker, Professor Campbell,* and M. Bélopolsky agree in locating the line in a position removed far to the red side of the chief nebular line. But, as we shall see hereafter, the light source was moving away from us, and just as the tone of the whistle of a locomotive is lowered in pitch as it rushes away from a listener at rest, so too analogously with light waves, if the source of light is receding from us the color tone will be lowered, and its luminous spectral rays thrown down towards the red in the scale of colors. Might not this cause have been operative in shifting the bright green nebular line some eight or ten places from its normal position? But Dr. Huggins confronted the analyzed light of the star in his spectroscopes with the spectrum given by nitrogen and the vapor of lead, the relative positions of certain lines in these substances to the chief nebular line being known with very great accuracy. Even allowing for the shift due to the velocity of the light source in the line of sight, the result of these experiments was to negative the existence of the chief nebular line in the spectrum of Nova. Nor was the second nebular line to be found in its spectrum according to the witness of most observers, although as with line 500,† so with line 495, there was a faint line suspiciously near in position, but not to be confounded with it. Professor Campbell saw such a line; Dr. Becker measured a line at 4947, Dr. Copeland at 4952.5, which however he states was not the nebular line; on one of the Stonyhurst plates, too, but on one only, there appeared a broad faint bright line at 4954. On the other plates the region in the immediate neighborhood of 495 is occupied by continuous spectrum with dark lines superposed upon it. Dr. Huggins also remarks the absence from Nova "of a very strong ultra-violet line which is usually found in the spectrum of the nebula of Orion."‡ Direct comparisons, too, of the spectrum with the hydro-carbon and carbon oxide flame and with magnesium led to negative results as to the presence of these substances in the star.

Before we proceed to discuss further what substances were probably represented in this remarkable spectrum, our attention

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* The position given to the line by this observer in a recently published paper, *Astronomy and Astro-Physics*, No. 109, p. 805, Nov. 1892, is 5018.

† One photograph of Professor Campbell's taken on Feb. 14, gave a line at 5007. (loc. cit.)

‡ *Loc. cit.* page 488.

is demanded by some other of its peculiarities. And first a great number of the brightest lines and noticeably all the hydrogen lines, were accompanied on their blue sides by a dark counterpart so that the appearance of the spectrum, considering these lines alone, was that of a series of bright and dark couples. This was indeed a curious fact, but more than this, upon the bright lines which had these dark companions, appeared thin dark absorption lines. Thus to take the F line of hydrogen on the Stonyhurst photographs as an example. Proceeding from blue to red, we have first a broad black absorption line of dark hydrogen, then a broad line of bright hydrogen which was divided unsymmetrically by a dark absorption line, the line of division leaving more of the brightness to the blue than to the red side. The line was finally terminated on the red side by a sort of nebulous wing. Turning now to the G′ or first violet line of hydrogen, we have the same broad divisions as in F, but with this difference, that each component of the bright G′ is subdivided by dark lines, the blue bright component by one, and the red bright component by two dark lines. Moreover, alterations took place, either by changes in the relative brightness of the two bright components of F, or by the incoming of sharp dark lines on the bright bands or of sharp bright lines on the dark bands, after the star had attained its maximum. This fact is testified to by the observations made or by the photographs taken at Tulse Hill, Potsdam, Stonyhurst, the Lick Observatory, Pulkova, and Harvard College. If the lines of any substance are thus doubled, and let us take the hydrogen line F as our example, it is clear that the normal position of the line in a body at rest must coincide with either the bright or dark component, or with neither. Wherever the normal position of the line F for example, might be with reference to the remarkable F line given by the Nova, the dark and bright hydrogen must have been in relative motion to one another. This relative velocity of the bright and dark gas was exceedingly great, about five hundred and fifty miles a second according to the measurements of Dr. and Mrs. Huggins, Professor Vogel and Father Sidgreaves. More remarkable still, there was no change in this velocity for more than a month.

It must be evident even to those who are least conversant with the niceties of spectroscopical researches, that before a map can be constructed from measures, made either with the telescope or from photographic plates, which shall accurately represent the true positions of the lines in any spectrum, we must needs settle with very great accuracy the true position of some fiducial or starting-point. Nor can any theory of the star, its constituents or its origin, be formulated unless the positions of the lines are absolutely correct. In the Nova the lines of hydrogen were certainly present. The spectrum of hydrogen can be very easily obtained in vacuum tubes by means of electrical excitation. The standard positions of the lines of hydrogen are also exactly known. One obvious method then of fixing a starting or fiducial point was to confront the spectrum of the star with the spectrum of hydrogen, and to determine where, for example, the F line of hydrogen as given by the tube was situated relatively to the enormously broad and complicated double F line of the star's spectrum. This was the method adopted by such experienced observers in this line of work as Dr. and Mrs. Huggins, and Professor Vogel. With regard to F, Dr. Huggins writes, "The line from the vacuum tube fell not upon the middle of the line (*i. e.*, the bright broad F in the Nova) but near its more refrangible (*i. e.*, blue) edge."* Professor Vogel states, "These three lines (*i. e.*, C, F and G′) did not exactly coincide with the lines of the comparison spectrum, but were displaced considerably towards the red, without, however, separating completely from the artificial lines, since they were very broad."† At any rate, from these statements it appears, and we may add the concurrent testimony of Eugen von Gothard, that the bright F of the tube did not fall upon the dark but upon the bright hydrogen, although Dr. Huggins would seem to place it slightly more to the red than Professor Vogel. Father Sidgreaves argued that the proper place for F on his photographs taken with a prism, would be that position in the complicated Nova line, which gave the proper wave-length intervals F to G′, and G′ to *h*, in other words which would give the best fit. He found after many and careful experiments that "the marginal separations of the bright and dark parts of the hydrogen broad lines at F, G′, and *h* are the only similar positions in each that give the correct wave-length intervals F-G′ and G′-*h*: in other words, the true positions of these lines are those which are common to both the bright and dark parts."‡ Thus he differs from Huggins and Vogel, who make the true positions of F, G′, *h*, as proper to the bright part, although indeed their positions are not very far removed from his. He also admits as telling strongly against him an observation of Professor Young made on the C and F hydrogen lines in a perfect instru-

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* *Loc. cit.* p. 486. The explanatory words in brackets in all quotations are ours.

† *Nature*, vol. 45, No. 1169, p. 498, March 24, 1892.

‡ *The Observatory*, No. 193, p 364, October, 1892.

ment of great dispersion. According to this observer "the lines were diffuse, like C and F from hydrogen under pressure; but the shading was sensibly symmetrical each way from the *middle of the line*."* · That is, with Huggins and Vogel the true position of F is in the bright line of Nova and proper to it, but still further removed to the red than they would place it. Starting from the middle of bright F we might arrange the order in the observations thus, Young, Huggins, Vogel, all making the fiducial point proper to bright F, and Sidgreaves placing the fiducial point as common to bright and dark F, and at the separation of the bright and dark lines.

We may now ask if the nebular lines, and the hydro-carbon bands are excluded from the spectrum, and in their exclusion Professor Vogel by direct comparisons concurs with Dr. Huggins, what spectrum most completely answers to the spectrum of Nova? We answer unhesitatingly the spectrum given by the chromosphere and prominences of our own Sun. First we have the full hydrogen series, which we have already pointed out has been observed even in its ultra-violet radiations by Hale and Deslandres as belonging to the solar prominences. Then the two bright lines at 5014 and 4921 which together with *b* formed the bright triplet in the green which was so conspicuous to all observers, are matched exactly by solar chromospheric lines. The characteristic Sun line D_3 was also present, the sodium couple D, and very probably one if not all the lines of the triplet *b* of magnesium. More than this, if we take the list of chromospheric lines of the Sun as observed by Professor Young and collate them with the bright lines of Nova, there is a striking accord both in position and character between the two sets of lines.† Nor does the likeness of the lines in Nova to those observed in the chromosphere and storms of glowing gases and vapours frequently observed in the Sun end here. For, to mention no others, M. Deslandres at Paris has observed in the lines which are brightened in the solar atmosphere precisely the same doubling of bright by black lines as was seen and photographed in the spectrum of the Nova. And, further still, the incoming of these bright or dark lines upon the broad dark or bright bands is perfectly represented in the spectrum of solar storms and Sun-spots. Again, with regard to the unsymmetrical division of some of the broad bright lines by

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* *Astronomy and Astro-Physics*, April, 1892.

† Father Sidgreaves first called attention to this point of the probable numerous coincidences of chromospheric and Nova lines at the May meeting of the R. A. S. See *The Observatory*, No. 189, p. 236. In his recent papers, *loc. cit.*, Professor Campbell gives a long list of such coincidences.

dark absorption lines, the same effect has been produced by Professors Liveing and Dewar in the laboratory in their experiments on the spectra of the vapours of metals. So that all the indications of the remarkable spectrum of the new star seem to suggest rather a solar chromospheric than a nebular analogy. It would be premature, however, to conclude that the new star was a body constituted like our Sun. Its feeble continuous spectrum, relatively to the intense luminous radiations of its atmosphere, would seem to preclude any such probability. More likely it might be specifically reduced to that class of variables, which includes stars such as γ Cassiopeiæ, β Lyræ, and η Argus, which likewise exhibit the bright chromospheric solar lines. In fact, with β Lyræ it has a very strong family likeness, for this star too gives a spectrum characterized by the same strange doubling of the bright and dark lines. Nor must we neglect the fact that when the Nova of 1876 was dying out, it showed this same line near 500, which if not the nebular line, can be so easily matched by a group of bright chromospheric lines.

We may now proceed with the history of the second appearance of this interesting star. We left it at the end of April as a faint glimmering of light in the Lick equatorial and reckoned to be of the sixteenth magnitude. It was, therefore, with somewhat of surprise that astronomers learned by means of a circular from the Rev. T. E. Espin, of the Wolsingham Observatory, that Mr. H. Corder had, on observing the place of the Nova on August 19th, ascertained that it had again increased in brightness, and was on that date of about the ninth magnitude. In other words, this remarkable object, which at the end of April had possessed but the 1-60,000th part of its radiative energy of the beginning of February, had again increased its brilliancy of August eight hundred and eighty-five fold. The Harvard College observers, who on April 26th gave to the star a magnitude 14.5, reckoned on the 24th by the Lick observers as of magnitude sixteen, now regarded the star during the month of August and the beginning of September as being of the tenth magnitude, the visual magnitude, contrary to what was before observed, being now somewhat greater than the photographic. From this last fact it can be inferred that the star's light was in great part of that quality which predominates in the visual part of the spectrum. On August 30th the Astronomer Royal's photographs made the star of the twelfth magnitude, while the visual observations of Freeman, Copeland, Küstner, Ristenpart, Burnham, Krueger, and others agreed in placing the magnitude about the number ten. Even on

September 14th it was about the same magnitude to Mr. Newall in the Cambridge twenty-five-inch telescope.

With regard to the spectrum, the Rev. T. E. Espin announced that its light was monochromatic and that the spectrum consisted of a brilliant line, the perplexing line in the green near 500. Herr Bélopolsky, at Pulkova, detected two lines, the one a green line, the mean of measures made on five nights placing it at 501, and the other too variable in brightness for satisfactory measurement. Dr. Copeland and Mr. J. G. Lohse, with the Dun Echt fifteen-inch refractor, measured the two lines as being situated at 5003 and 4953, in other words, they seemed to be the two lines characteristic of a gaseous nebula. Subsequent observations revealed a distinct line in the yellow near 5801, about the place of a line seen in 1876 in Nova Cygni, and to be found in a certain class of bright line stars. The star also showed a faint continuous spectrum in the green. Herr Bélopolsky also recognized a yellow line, which he presumed to be D or D_3, F of hydrogen was also visible, and a dark line about 465. In the Cambridge twenty-five inch Mr. Newall saw a bright line near C of hydrogen, three bright lines close together in the green, a faint bright line in the blue presumably F of hydrogen, and a still fainter line in the violet. The continuous spectrum was recognized, but no dark lines. Later observations showed the line in the red, and the green triplet, while the blue and violet lines had faded away. Finally, on October 14th, the red line being fainter, the yellow line, possibly 5801, was brighter. These observations of Newall are important as connecting the general appearance of the spectrum of this tenth magnitude star with that observed on March 24th by Dr. and Mrs. Huggins, when the star had fallen to nearly the eleventh magnitude. For on that date "the four bright lines in the green were distinctly seen, and appeared to retain their relative brightness; F the brightest, then the line near *b*, followed by the lines about 5015 and 4921. Traces of the continuous spectrum were still to be seen."* Turning now to the photographs of the spectrum, Professor Pickering, whose plate of March 21st gave the hydrogen lines G′, F, H, *h*, in the order of brightness named, on September 2nd photographed two lines of equal brightness, G′ of hydrogen, and the other near 500. Herr Gothard, at Hereny, compared his spectrograms with the lines given by the bright-line Wolf-Rayet stars, and the Ring nebula, with the result that a satisfactory agreement was detected between them. Finally Professor Campbell, at Lick, observed or

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* *Loc. cit.* p. 492.

photographed eleven lines, among them being the hydrogen lines F and G′, and at least nine of the eleven lines, according to his measures, being found in the nebular, or bright-line star spectrum.[*] The lines 5002, 4953, and 4857 he regards "as undoubtedly the three nebular lines, displaced towards the violet. . . . The nebula is therefore approaching us with a velocity of at least one hundred and seventy-five miles a second."[†] Professor Barnard too recognized with the Lick equatorial the visual appearance of a planetary nebula in the new star, a result, however, which neither Mr. Newall or Mr. Roberts can succeed in verifying with their instruments, while Mr. Newall suggests a very plausible explanation for the nebulous appearance of the star in the Lick telescope.[‡] Must we then conclude that the Nova has become a planetary nebula? In spite of the great and acknowledged skill of Messrs. Campbell and Copeland in spectroscopic researches, we remain not quite satisfied on the point. And first we must remember that the star at its second outburst was very faint, and that to measure the position of bright lines in a very faint star is by no means an easy matter, although it may be justly urged that in the present case the measures of the two green nebular lines as given by the two independent observers are most concordant. In the next place, of Professor Campbell's list of eleven bright lines, which are found in nebulæ, seven are recorded as covered by, or lying upon the edges of bright lines photographed at Stonyhurst in February, while another is very close to the position of a line measured by Dr. Becker in the same month. In fact, the only line that cannot be satisfactorily accounted for is the conspicuous green line near 500. But even with regard to this line the mean of Bélopolsky's measures place it at 501, very near indeed to its old position, while to Campbell himself it seemed, in a powerful grating spectroscope, to be a very broad line or band. We may also remark with regard to 495 that the map drawn by Dr. and Mrs. Huggins, in March, shows two lines very close to this position. Then we have the similarity in general appearance of the spectrum of the waning and waxing star, as witness the observations of Dr. and Mrs. Huggins and of Mr. Newall, and finally the testimony of the Lick observer, that when observed in August the "continuous spectrum presents the ap-

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[*] In a more recent paper, *Astronomy and Astro-Physics*, November, 1892, he records the identification of the two outstanding lines in nebular spectra.

[†] *Astronomy and Astro-Physics*, October, 1892.

[‡] The opinion of observers at the November meeting of the R. A. S. seemed to be that the telescopic appearance of the star was unlike that of other stars in its neighbourhood, though it could not with certainty be described as a planetary nebula.

pearance of containing a large number of bright lines, just beyond the power of the telescope to define."* At least then we may conclude that the evidence, and the probability founded thereon, of the spectrum of August and September containing the nebular lines, is of much lower weight to the almost concurrent evidence of observers, and the corresponding high probability of their non-existence in the earlier spectrum.

But how are we to account for the various phenomena optical and spectroscopical presented by this remarkable new spot of light in the Milky Way? For any theory of the new star's origin and physical constitution must needs find an explanation for the sudden outburst of light, for the fluctuations, the wanings and the waxings of the light, for the wonderful spectrum, its extent, its multitude of lines, its complexity, the bright lines with their dark companions, the enormous relative velocities indicated by the same, and the long continuance of these velocities without any appreciable alteration. Swarms of meteorites meeting at a level crossing are excluded by the absence of the carbon and magnesium lines or bands from the spectrum. So too are all theories based on the assumption of a star rushing away in our line of sight and moving through a nebula coming towards us, for the nebular lines were not present in the earlier spectrum, and their appearance in the later spectrum is problematical or at least not proven.† But in discussing the spectroscopic appearance of the star we have pointed out the many analogies with the spectrum of the solar chromosphere and prominences, and, be it remarked in passing, the hydrogen spectrum, whatever else was present, was a marked characteristic of the later appearance of Nova. Was it due then to two bodies composed of materials like our Sun colliding in space? In that case the energy of motion being converted into energy of heat, the solid bodies would form a violently agitated and rapidly expanding gaseous mass, which, after a series of contractions and expansions, would finally become a Sun-like orb. The initial outburst of light might thus be accounted for, but it is difficult to see, the total amount of radiative energy remaining the same, how the fluctuations of the star's light and its rapid dissipation could be thus explained. But if the conversion of external energy of motion into energy of heat is excluded, we must turn to the pent-up internal energies of the heav-

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* *Loc. cit.*

† After reading Professor Campbell's more recent papers we are inclined to modify this opinion, and to think that if the later spectrum contains lines near 500 and 495, then they were probably present in the earlier spectrum, but masked by dark bands, as indeed some observations mentioned above seem to indicate.

enly bodies, to inquire how they could be liberated. This is Dr. Huggins' explanation of the phenomenon, a further advance on a theory due originally to Klinkerfues and afterwards developed by Wilsing. Conceive two bodies in different stages of evolution, but still of the solar class, to be travelling through space with enormous speed, such a speed as puts at defiance the universal law of gravitation, accepting the word universal as limiting the application of the law to our own known system or universe, such a speed as is displayed by the so-called run-away stars Arcturus and No. 1830 of the catalogue of Groombridge. Moreover, let us postulate that they are moving in hyperbolic orbits, and again that these orbits are performed in planes not very much, if at all tilted to our line of sight, these last two postulates being well within the limits of possibility. What will occur if furthermore these two bodies pass sufficiently close to one another. On the Klinkerfues-Wilsing hypothesis, they will mutually deform one another, set up tides in the gaseous materials of which they are composed, and induce such differences of pressure in their respective atmospheres as will be capable of producing enormous eruptions from the hotter interior layers of the two globes. Thus would the chromospheric lines, the number of lines, the hydrogen spectrum, the reversal phenomena, the sudden outburst of light, its fluctuations, and its final waning be accounted for. And the two stars are only to be supposed to be rushing the one towards us, and this one giving the dark lines superposed upon the faint continuous spectrum, and the other, which gave the bright lines, receding from us, and we have the curious matching of bright by dark bands, and the observed displacement of the lines from their normal positions. The permanence of this displacement can be met by the assumption of the motion of the two bodies as having taken place in hyperbolic orbits, so that after their swing round one another, the components of their velocities in the line of sight would continue nearly constant for a long time.

But these high velocities and their continuance without apparent change for several weeks, as well as the one body having been, so to speak, a dark replica of the other, are very great difficulties in the way of the acceptance of Dr. Huggins' theory in its entirety. Accordingly Father Sidgreaves has proposed a modification of the theory, by which we get rid of these somewhat unsatisfactory factors. The foundation, however, of his explanation rests upon the fiducial line F being at the point common to both dark and bright F in the Nova and not in the bright F, a question which we have already sufficiently discussed, and the bearing of which upon the theory of the new star is important. According to Father Sidgreaves then, the original upset of equilibrium may be attributed to the casual passing of one body near another, as actual collision seems to be excluded, but the whole of the phenomena visual and spectroscopic are to be attributed to the light of one body, and not to the integration of the light of two. In other words, we have a cyclonic storm similar to those seen in the Sun, but on a very much greater scale. "A great cyclonic storm of heated gases would produce this double effect (*i. e.*, the dark lines matching the bright lines), if the heated gases were rushing towards us in the lower depths of the atmosphere, trending upwards, and returning over the stellar limb. In the lower positions the advancing outrush would be screened by a great depth of absorbing atmosphere (hence the dark lines), while as a high retreating current its radiation would be along a clear line to our spectroscopes" (the corresponding bright lines).* Certainly M. Deslandres has seen such appearances in solar prominences, while other solar observers can testify to the reversals of lines in prominence and Sun-spot spectra corresponding to those observed in the bands of the Nova. Nor are the velocities on this hypothesis greater than some observed in solar storms by Father Fényi of the Observatory of Kalocsa. But a difficulty is furnished by the case of the star β Lyræ. It too shows these curious dark and bright companion lines, but the bright lines, according to Professor Pickering, alternately and periodically appear right and left of the corresponding dark lines. We cannot possibly suppose this periodic shifting to be the result of periodic storms, with the bright gases alternately rushing up and down. Other considerations too seem to show that the fluctuations in the light of β Lyræ are due to the action of two bodies. And β Lyræ is a variable star, so too is T Coronæ, the new star which appeared in 1866, and was the first to be subjected to spectroscopic analysis, and which also showed the dark flutings characteristic of Secchi's Type III of stars, to which type or class a very large proportion of variables are to be referred. Again the Sun itself is a variable star, the variation of light and heat being, it is true, on a small scale, but yet the curve of Sun-spot frequency bears such a striking resemblance to the light curves of many variables, that it is impossible not to see a common or related cause for the phenomena of spot-variation in the Sun and light-variation in the stars. So that the Sun may be connected through the link of variability both with temporary and variable stars. And yet the Sun ac-

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* *The Observatory, loc. cit.*

cording to the celebrated speculation of Kant and Laplace, a speculation which has received in these later years a much firmer basis of probability from the thermodynamic calculations of Lord Kelvin and Professor Helmholtz, and from the knowledge of the cosmos acquired by means of the camera and the spectroscope, was originally formed from a gaseous nebula. If then it should be established that the Nova of 1892 really re-appeared after its first decline in light as a planetary nebula, and, be it noted, that of 1885 appeared in the midst of a nebula, have we in our spectroscopes and telescopes been watching the genesis of a nebula from a prior state of matter, which will perhaps in its turn be ultimately formed into a Sun and its attendant planets? Many problems then of intense interest are suggested by the new star in Auriga, and yet, although our knowledge of these rare and temporary appearances in the heavens has been vastly increased by its advent, we must fain confess that it has also accentuated our ignorance of the ways by which the Divine Intelligence works out His wonderful plans. What then are we to think of those who like Strauss and his followers in Germany, and their more recent English imitators, boasting of a knowledge of the formation of the universe which is not warranted by exact science, use it to attack the Mosaic account of the creation which is given in the first chapter of Genesis, on the interpretation of which theologians and exegetists are by no means agreed, and thence with rare philosophical acumen deduce that science and revelation are in antagonism the one with the other. "And God said; Be light made. And light was made." And although the Divine Wisdom is not limited by any possible ways we may conceive of for the first dawning of light in our system, yet perhaps the method selected was like to that which resulted in the appearance of the new star of 1892 in the outskirts of the Milky Way.

THE SOLAR CHROMOSPHERE IN 1891 AND 1892.*

WALTER SIDGREAVES.

The mean height of the chromosphere was notably above the annual average on June 9 and June 11 of 1891, and on June 3, Sept. 4, and October 22 of 1892.

Extensive elevations have been frequent during the past year, and have not been confined to any particular position with refer-

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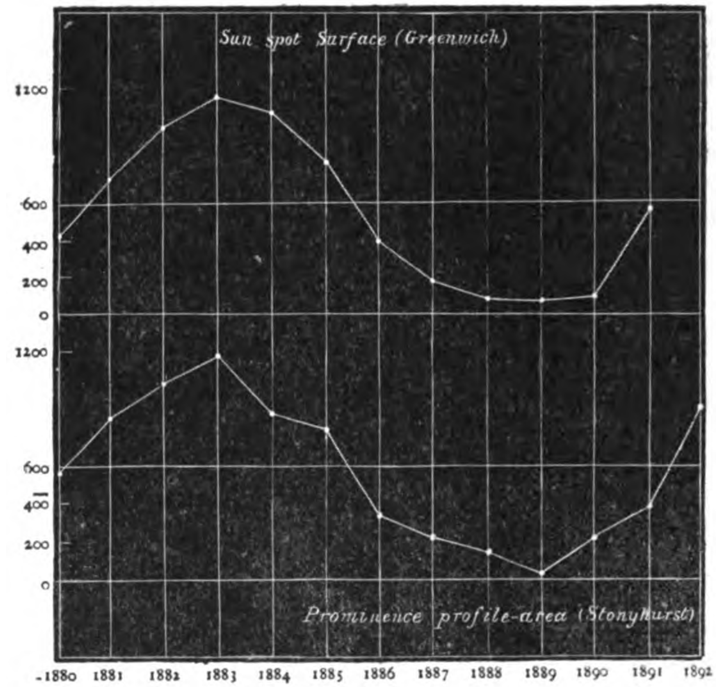
* *The Observatory*, March, 1893.

ence to the solar equator. The most remarkable of these were observed on June 3 and October 22. On June 3 the measures show an elevated region extending from 29° on the west side to 35° on the east side of the north pole, and another between 4° and 30° on the east side of the south pole. On October 22 four such regions were observed at mean latitudes 51° and 27° in the N.E. quadrant, at 20° in the S.E. quadrant, and at 79° in the S. W. quadrant, covering respectively 10°, 22°, 8° and 26°.



Referring to previous years we find that the last maximum period of the spot-cycle was also remarkable for the number and extent of these elevations of the chromosphere; and that the intervening minimum period was marked, in the opposite sense, by chromospheric depressions. It further appears, from the observers' notes, that during the maximum period of 1882-83 the chromosphere was on the whole brighter, and in the minimum year 1889 it was fainter than usual; and we have, at a date which may be very near the actual maximum, Nov. 30, 1882, the singular record of the C line doubly reversed on the chromosphere nearly all round the limb. We are now approaching a new maxi mum, and in the past year the chromosphere has been growing in brightness.

Chromosphere in 1891.

	No. of days of observation.	Mean height of chromosphere excluding prominences.	Mean height of prominences.	Mean extent of prominence in arc.		Highest prominence.
		″	″	°	′	″
January	1	8.54	17.09	2	0	17.09
February	5	8.03	31.52	17	53	111.07
March.	0					
April	1	8.54	28.19	13	39	46.99
May	3	7.99	19.40	8	34	53.40
June	6	8.55	29.90	21	23	76.90
July	4	7.05	20.94	10	4	51.26
August	2	6.83	23.50	13	14	39.73
September	7	7.39	29.43	30	45	72.62
October	7	7.26	28.19	13	36	76.47
November	0					
December	2	8.12	30.33	15	42	102.11
Mean for ten months	3.8	7.83	25.85	14	41	64.76

Chromosphere in 1892.

	No. of days of observation.	Mean height of chromosphere excluding prominences.	Mean height of prominences.	Mean extent of prominence in arc.		Highest prominence.
		″	″	°	′	″
January	6	7.69	31.27	22	43	66.64
February	6	8.20	27.98	22	46	64.93
March	7	7.43	33.32	18	34	158.49
April	5	7.43	27.25	22	38	58.96
May	8	7.65	31.82	23	31	88.86
June	9	7.89	28.32	39	17	76.90
July	7	8.24	24.35	30	1	62.37
August	2	8.33	25.42	35	35	46.99
September	2	8.54	28.41	41	49	106.80
October	4	8.54	27.89	42	27	64.08
November	2	7.69	32.46	42	43	93.98
December	6	7.60	27.55	27	49	93.98
Mean for the year	5.3	7.94	28.84	30	49	81.92

The annual means of the prominence-measures show that these have been increasing in number, height, and extent since 1889; and the accompanying curves show that the annual mean profile-areas of the prominences follow very closely those of the mean spot-areas. The profile-areas of the prominences are expressed in minutes of visual arc; but the scale unit has been made 3.7 times that of the comparison-curve, in order to bring the mean ordinates of the two curves to the same length. The spot-areas, expressed in millionths of the visible hemisphere, have been taken from the Greenwich observations, and those belonging to the unpublished volumes for 1890 and 1891 have been kindly supplied by the Astronomer Royal.

STONYHURST Observatory, Lancashire.

THE MODERN SPECTROSCOPE.

VII.

The Spectroscope of the Royal Observatory, Edinburgh.[*]

L. BECKER.

The optical part of this instrument is the same as has been used at Dun Echt Observatory for several years. The Sun's rays, after reflection by the heliostat, fall on an object glass of 6 inches aperture and 7 feet focal length, which forms an image of the Sun on the slit attached to the collimator. By two endless cords the observer can correct the position of the heliostat without going outside the hut. The slit is formed by two plates of platinum with both jaws opening simultaneously by the motion of a screw. By a rack and pinion the slit can be brought into focus of the collimating lens. The latter has a free aperture of 4 inches and a focal length of four feet. Two feet in front of it the Rowland grating stands on the face plate of the recording apparatus. It is fixed in a brass frame with a T footpiece, with levelling screws at the ends. The Rowland grating—a present from the Johns Hopkins University at Baltimore to the Earl of Crawford's Observatory—contains 14,438 lines to every inch, ruled on speculum metal, its ruled surface being 5.5 by 3.5 inches. Although there is a slight difference in the focus of the spectra on either side of the normal, we are convinced that the irregularities in ruling which cause this defect have been without influence on this work. This is satisfactorily shown by the fact that close double lines which were separated by Professor Piazzi Smyth with similar optical appliances, were found to be double and well defined at Dun Echt. Moreover, a great number of faint lines, never recorded

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[*] *Trans. Roy. Soc.* Edinburgh, vol. XXXVI, Part I, No. 6.

before, were observed on both sides of the normal of the grating, their reality being often abundantly established by their increased intensity in a low Sun.

The different rays are received by the 4-inch object-glass of the viewing telescope, of which the focal length is 4 ft. 11 in. There is a filar micrometer provided with two cross wires inclined 45° to the horizon. Their intersection serves as the zero point. An eye-piece, with a magnifying power of 120 diameters, was employed on all occasions. The viewing telescope forms an angle of 25° with the collimator. Each is supported on a separate concrete pier.

The recording apparatus consists of two distinct parts, one for magnifying the angular motion of the grating, and the other for recording the corresponding arc on a broad fillet of paper. The grating stands on a plate attached to the same vertical axis as a 6-inch worm-wheel (A) of 180 teeth. This wheel is turned by a tangent screw (*a*) on the end of a half-inch steel rod 12 inches in length, the other end carries a 12½-inch gun-metal wheel (B) with 150 teeth. The position of the rod can be adjusted so as to insure proper contact of the screw with the worm-wheel. A system of wheelwork turns the wheel B. The latter is geared into a 1¾-inch pinion (*b*) of 15 teeth, on the axis of which a second wheel (C) of 11½ inches diameter and 140 teeth gears with a second pinion (*c*) of the same dimensions as the first. The two horizontal axes of *b*, C, and *c* are clamped in the slot of an adjustable bracket. All these appliances are attached to a strong mahogany frame, 2 feet square by 2 feet high, provided with three foot screws, and carried by a massive concrete pier.

It is apparent that the angular motion of the second pinion (*c*) is

$$180 \times \frac{150}{15} \times \frac{140}{15}$$

equal to 16,800 times as large as that of the grating. By a long ⅜-inch iron rod the second pinion can be turned by the observer from the eye-end of the viewing telescope.

The rod, however, is not fixed immediately to the pinion, but transmits its angular motion by a very useful kind of joint, without communicating any longitudinal vibration. It is employed by Mr. L. Casella in his recording anemometers, and was introduced here at the suggestion of Dr. Copeland. Two square bars are screwed crosswise together, each of which fits exactly without tightness into a deep groove in a corresponding disk. The grooved surfaces of the disks face each other, and turn in parallel

planes, the only connection between them being the glidin
If the axes of rotation be parallel, although not necessaril
same line, the transmission of rotary motion from one
other is perfect. To prevent the cross from altering its p
rotation one of its bars has a projecting plate which slides
row channels at the back of the groove of the correspondi
In our instrument one of the disks is carried by the second
(*c*), while the axis of the other is supported by the pillar
viewing telescope, and is connected with the long iron r
Hooke's joint.

Underneath the eye-end of the viewing telescope, the ot
of the iron bar is attached, by another Hooke's joint, to
of a wooden "recording" wheel. This wheel, which is 6
in diameter, rotates inside a narrow box in such a way
rim, 2 inches in breadth, is level with the outside of the lid
box. Above the exposed part of the recording wheel is a
swing frame carrying a roller of the full breadth of the
Both wheel and roller are covered with sand paper, to i
grip on the paper fillet which passes between them. A
about five pounds is sufficient to prevent slipping. When
ing, it is by turning this roller that the grating is move
paper, 1⅞ inch wide, is supplied from a large roll inside t
and passes through a slit in the lid and over a flat surface
wheels. On the lid, turning on a common axis, are five re
levers provided with prickers at their free ends. The
which form dots in a straight line across the fillet about
apart, are easily worked by the thumb and fingers of on
either singly or simultaneously. To this end the levers a
ably splayed at the fulcrum ends. The levers are smartly
by springs as soon as the pressure is removed. Thirty-on
ent records can be made by the various combinations of
needles, but only 19 have been employed. The full revolu
the recording wheel are registered in a simple manner. A
nail was driven into the rim of the wheel, and filed aw
sharp edge, which leaves a distinct mark on the paper eve
it passes beneath the roller. These marks served as zero
in reading off the observations. We may mention that
3500 feet of paper that contains the observations, not
these marks is wanting; and, judging from the intervals b
them, the fillet has never once slipped. Apart from this sa
the observer, when turning the roller, could always see
viewing telescope that the grating had moved; and thi
not possibly happen unless the fillet had correspondin

nced. If the recording wheel was intentionally held fast it was possible to draw the fillet over it by turning the roller.

\s to the linear distance between two lines on the paper, it may sily be computed from the figures given, that the D lines for innce are 19¾ inches apart, whilst the whole region from λ 6024 4861 would require a strip 314 feet long.

Γhe apparatus works in the following manner:—The observer th his right hand turns a toothed wheel on the same axis as e roller; this drives the recording wheel and moves the paper ong by friction. The long iron rod transmits this motion to e disk of the connecting joint, and then by means of the cross the other disk which is fixed to the second pinion. This second iion, acting through the wheels and endless screw, slowly rotes the grating, thus causing the lines of the spectrum to move ross the field of view. When the line under observation coinles with the intersection of the wires, the fingers of the left nd depress one or more of the needles according to the degree blackness of the line. If the lines of the spectrum are near tother, they can be registered as quickly as the eye can appreciate eir individual characteristics.

In spite of all the connections and the smallness of the wormheel, the probable error of one observation of the relative posion of the grating is but ± 0″.77 of arc as computed from lines lf-way between standard lines. This corresponds to $\frac{1}{90000}$ inch the circumference of the worm-wheel.

For effecting a quick motion of the grating, the bracket to hich the wheelwork is fastened turns round a pivot at the upper d, and can be raised out of position by a string. By a long ooden handle the observer can then rotate the tangent-screw rectly, without quitting his seat at the eye-end of the viewing lescope.

The instrument could be much simplified. A small table movg easily round a vertical axis from which a rigid arm projects far as its rigidity permits, and of course balanced, and a secrw low pitch acting on the arm similarly to the slow motion of a ansit-circle in declination, would be a simple substitute for all ır multiplying gear.

Vhen a great number of lines have to be determined by eyeoservations, such an instrument will always give accurate relts in a comparatively short time, provided it is possible to troduce a sufficient number of standard lines.

STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

A recent examination of photographs of stellar spectra t
at Cambridge, and at Arequipa, has resulted in the discove
several interesting objects which are enumerated in the follo
table. The designation of the star is given in the first co
and is followed by its approximate right ascension and de
tion for 1900, its magnitude, and a brief description of its p
graphic spectrum.

Designation.	R. A. 1900		Dec. 1900		Magn.	Description.
	h	m	°	′		
B. D. + 49° 41	0	12.2	+ 49	44	9.4	Type IV.
B. D. — 13° 893	4	24.5	— 13	17	5.8	F line bright.
A. G. C. 5429	4	43.8	— 36	23	7½	Type IV.
A. G. C. 11890	8	42.4	— 29	21	7½	Type IV. [l
—— ——	15	27.0	— 71	32	—	Type III (Hydrogen lin
A. G. C. 22838	16	47.9	— 44	50	8.2	Type V (Bright lines).
Z. C. XVIII^h 56	18	3.3	— 63	38	9½	Type III (Hydrogen lin
A. G. C. 26129	18	59.7	— 38	17	8½	Type IV? [l
B. D. — 21° 6376	23	6.3	— 21	32	9.0	Type IV.

A. G. C. 11890 was found by Mr. A. E. Douglass in an ex
ation of the photographs taken in Peru before they were se
Cambridge. This object is probably identical with No. 29
list published in the *Astronomische Nachrichten*, Vol. XCIX
which is there erroneously announced as U. A. Pyxis, 34, m
tude 6.5. The spectrum of the latter star is of the second ty

The star of the ninth magnitude whose approximate po
for 1900 is in R. A. 15^h 27.0^m, Dec. — 71° 32′ has a spectrum
ilar to that of variable stars of long period. The photog
charts of this region show a slight variation but the mate
not sufficient to regard the variability as confirmed.

A.G.C. 22838 has a spectrum similar to that of the brig
stars in Cygnus and increases the known number of these o
to fifty-one. Its galactic longitude is — 2° 7′ and its galacti
tude is 308° 47′.

Z.C. XVIII^h 56 has a spectrum similar to other known
bles of long period. Photographic charts of this region
therefore examined and resulted in the confirmation of varia
of this star. Measurements of photographs, taken on Aug
August 13, August 20, September 4, 1889; June 12, Ju
1891, and September 17, 1892, gave for it the photog
magnitudes 8.1, 8.1, 8.1, 9.0, 7.6, 7.6 and 7.9.

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[*] Communicated by Edward C. Pickering, Director of Harvard Coll
servatory.

hotographs have also been obtained of the spectra of U ginis, V Boötis, S Geminorum, T Cassiopeiæ, R Piscis Ausi, and T Geminorum, which show them to be of the third e having the hydrogen lines bright. The photographic specm of the variable star of the fourth type, R Leporis, has also n obtained.

ARVARD COLLEGE OBSERVATORY,
May 10, 1893.

THE GEOMETRICAL CONSTRUCTION OF THE OXYGEN ABSORPTION LINES GREAT A, GREAT B, AND α OF THE SOLAR SPECTRUM. *

GEORGE HIGGS.

n the early part of August, 1890, the photographic work of normal solar spectrum which I had undertaken had been car- l as far as great A, or the limit of visibility in the red, and to 350, or beyond *z* in the invisible regions.

uring the two previous months of continuously dull weather, ile classifying and comparing results, I was interested, on king a close examination of the head portion of the A line, find the symmetrical construction, the rythmical grouping, the monic order of sequence, and other characteristics of the B repeated here in every detail.

hese two bands, together with alpha, are composed of a num- of doublets or pairs, which approach each other on the more angible side with uninterrupted regularity, finally crossing, and the limiting edges of all three bands the three last pairs over- each other.

he differences of wave-length between the components of pairs rease in the same order.

hese and other properties, which will be referred to, are still re obvious in the trains or flutings.

rom its holding an intermediate rank in each of its distinguish- characters I was induced to adopt B as a typical group in a metrical representation, and to investigate the subject by ans of rectangular co-ordinates.

efore a complete analysis could be made out, a micrometer l to be completed. This consisted of a platform, serving as a te holder, which was made to travel on runners between par-

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* Communicated by the author. Read before the Royal Society.

allel ways by means of a screw of such a pitch as to move t gative from one division of the scale to the next, for one revol of the divided plate on the screw head, this latter being d into 100 parts.

On and over the platform, a microscope is mounted with motions at right angles to each other; an index of glass and reflector complete the apparatus.

Over 1000 measurements of nearly two hundred lines have made, 100 of which belong to great A.

In the analysis the axis of x is assumed to occupy a po coincident with, or parallel to, the scale of $1/10^{10}$ m. units the positions of the various lines are set off on this scale (s 1) for the group, which is divided into four series. Ordinate then drawn in the position occupied by each line. The axi is divided into a number of equal parts, 1, 2, 3, n. Lines pa to the axis of x, drawn from each of these divisions, int the respective ordinates. The continuous curve passing thr the points of intersection is found to possess all the prop of a parabola.

Three points at least are selected to determine the positi the vertex and value of latus rectum. The distance from t igin along y is also found for an ordinate to the first line series.

Now, from the equation to the parabola $y^2 = px$, the for $\lambda = V + \frac{(n + c)^2}{p}$ is derived, where V = the wave-length in m. units of a point in the spectrum coinciding with the vert the curve; p, the latus rectum; n, any number of units, reck from the origin; c, a constant.

In practice a representation more suitable for lantern p tion being desirable, two units are taken on y for each line series; the equation then becomes

$$\lambda = V + \frac{(2n + c)^2}{L},$$

where L = $4p$, and c has twice its former value.

The computed places in the tables are derived from the tion in the latter form; the maximum want of agreement bet these and the observed positions not exceeding (for α a 0.015 tenth-metre.

In the case of A the agreement is not quite so close, the mum difference being about 0.05 tenth-metre.

It might be supposed that the greater difference arose fro certainties of observation, caused by the greater haziness and breadth of the lines composing the A group; but it so happens that each component is in itself so much of a double as to show a bright rift in the centre, which facilitates the centralisation in some degree.

The differences referred to are attributable to the fact that the curve for any series in A, B, or α is not rigorously parabolic, but one which cuts the parabola in three points, similar to the curve of sines, cutting a straight line and terminating in the same phase as at the origin. This difference is so extremely minute in B (and in α still less) that it would require a representation more than 10 feet square, or a good sized lantern screen, to show two separate tracings at a point of maximum divergence, assuming the tracings to have but a breadth of 1/100th of an inch.

Following the stronger doublets in the fluting or train of A on the less refrangible side, is a secondary train of thinner, sharply defined, doublets, which, with a solar altitude of about 10°, may be traced on the photographic prints to about the 12th position. This series, which was not previously known to exist, conforms to the same formula, and in the table of wave-lengths is denominated the "Secondary Train of A." This secondary train follows in the wake of the right component of the primary series. In the head, however, similar secondary groups follow in the wake of both right and left components, overlapping and interlacing each other in such a manner that their resolution into series can only be arrived at by deductive processes; the difficulty is increased by the fact that a large number of positions are occupied by the dense lines of the main band.

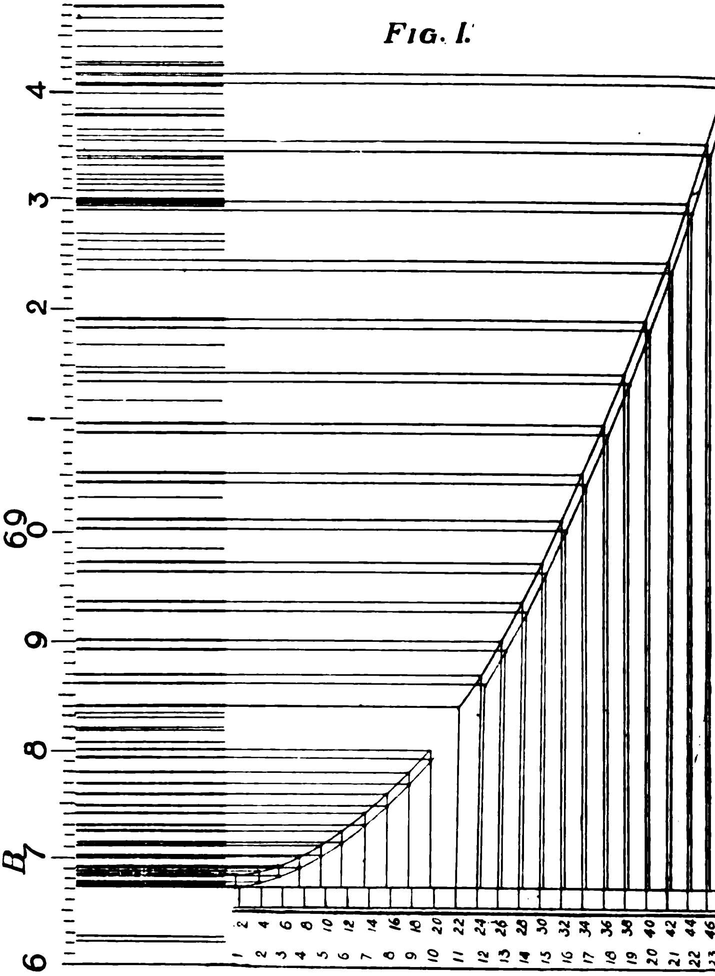
These two series will be referred to as "Sub-groups" in the head of A. They are, with two or three exceptions, given in a fragmentary state. At the same time, there is nothing to prevent their hypothetical positions being carried further, except that the greater density of the principal series precludes the possibility of obtaining any check in regard to their conformity.

Generally, a couple of numbers of the head bands are common to two separate series; this arises from their complexity being suggested by the nature of the analysis, and, as a matter of fact, some of these have been observed as doubles by Professor Rowland, of Baltimore.

In all cases of this kind a greater density is observable on the prints, and is doubtless the cause of the extra density of 7608.83, which belongs to two sub-groups; the line 7610.10 is known to be a double, but cannot with safety be measured as such.

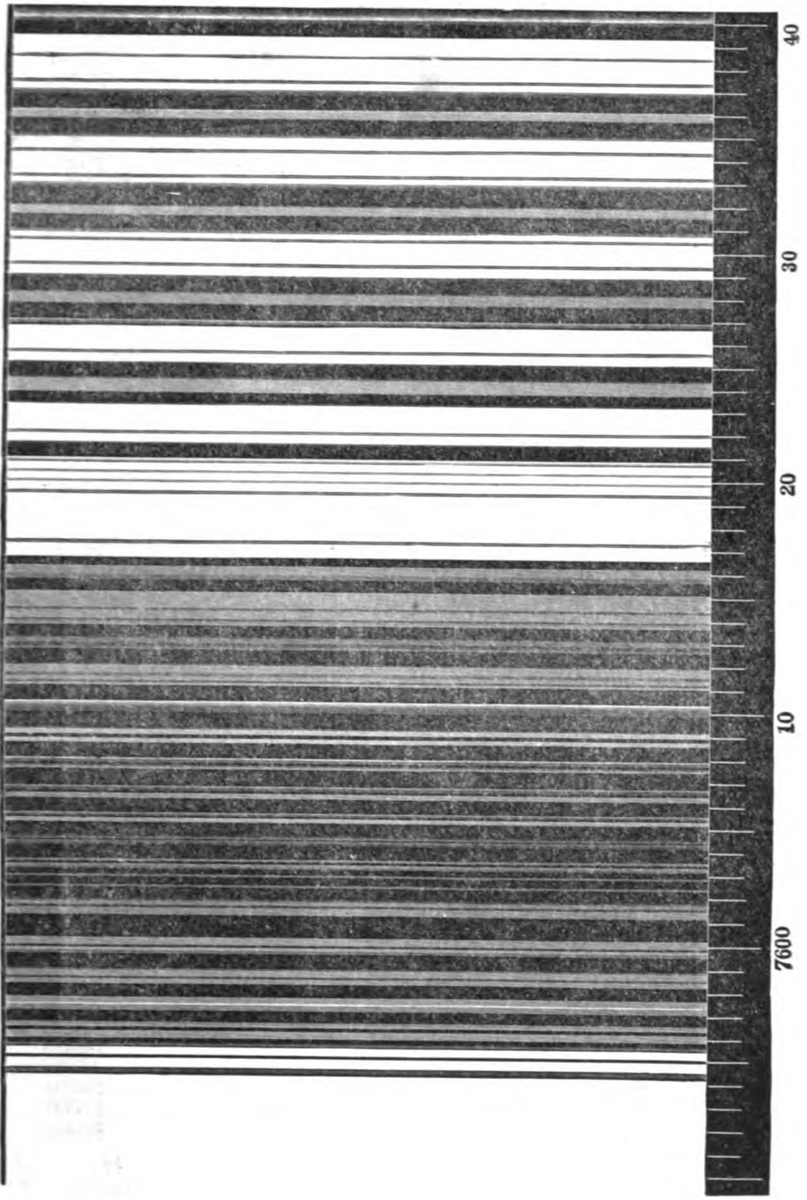
Owing to their incompleteness, the elements of the curv the sub-groups in head of A have not been made out, but a at their second differences is sufficient to establish their ment with the preceding form, since an interval is eq $d' + (n-1)\,d''$, where d' and d'' are first and second differ and n any interval from the commencement of the series.

Fig. I.



Note.—Since writing the above I find that Mr. Joh Stoney has written a note which was published with a pa Dr. Huggins on the spectrum of hydrogen, in which he re the conditions under which members of a harmonic series fall near to, but not on, a curve.

Fig. 2 is an enlargement of part of A.


40
30
20
10
7600

HEAD OF THE ALPHA LINE.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	6276.792	6276.798	6277.652	6277.644
2.	77.020	77.013	77.845	77.856
3.	77.514	77.518	78.190 78.280 78.370	78.335
4.	78.275	78.190 78.280 78.370	79.084	79.082
5.	79.302	79.302	80.095	80.095
6.	80.596	80.594	81.374	81.375
7.	82.156	82.148	82.924	82.922
8.	83.983	83.990	84.735	84.736

$V = 6276.775$
$L = 30.019$
$c = -1.29$

$V = 6277.632$
$L = 29.964$
$c = -1.41$

TRAIN OF THE ALPHA LINE.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
9.	...	...	6287.935	6287.942
10.	6289.596	6289.591	90.411	90.408
11.	92.344	92.350	93.140	93.141
12.	95.356	95.360	96.141	96.140
13.	98.634	98.640	99.416	99.407
14.	6302.176	6302.178	6302.941	6302.940
15.	05.984	05.980	06.741	06.740
16.	10.056	10.040	10.795	10.806
17.	14.394	14.399	15.135	15.140
18.	18.996	19.008	19.750	19.740

$V = 6276.693$
$L = 30.19$
$c = -0.263$

$V = 6277.746$
$L = 29.985$
$c = -0.515$

HEAD OF GREAT B.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	6867.464	6867.455	6868.457	6868.464
2.	67.776	67.788	68.782	68.771
3.	68.338	68.337	69.330	69.326
4.	69.150	69.148	70.130	70.130
5.	70.212	70.220	71.180	71.182
6.	71.523	71.530	72.485	72.484
7.	73.084	73.080	74.039	74.033
8.	74.895	74.892	75.834	75.831
9.	76.955	76.950	77.879	77.877
10.	79.266	79.274	80.170	80.172

$V = 6867.394$
$L = 32.03$
$c = -0.5$

$V = 6868.397$
$L = 32.194$
$c = -0.53$

TRAIN OF GREAT B.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
11.	...	...	6884.077	6884.090
12.	6886.012	6886.000	86.998	86.990
13.	89.181	89.182	90.140	90.142
14.	92.601	92.615	93.560	93.545
15.	96.271	96.277	97.200	97.201
16.	6900.192	6900.193	6901.120	6901.108
17.	04.364	04.368	05.264	05.267
18.	08.786	08.786	09.680	09.678
19.	13.458	13.444	14.334	14.340
20.	18.382	18.367	19.245	19.255
21.	23.555	23.545	24.412	24.421
22.	28.980	28.980	29.840	29.839
23.	34.655	34.662	35.518	35.509
24.	40.580	40.580	41.430	41.431

First series:
$V = 6867.529$
$L = 31.922$
$c = + 0.29$

Second series:
$V = 6868.812$
$L = 31.767$
$c = + 0.03$

HEAD OF GREAT A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
1.	7593.980	7593.98	7595.26	7595.260
2.	94.276	94.28	95.42 95.54 95.66	95.543
3.	94.796	94.79	96.05	96.050
4.	95.540	95.42 95.54 95.66	96.78	96.781
5.	96.508	96.49	97.73	97.736
6.	97.700	97.69	98.90	98.915
7.	99.116	99.12	7600.29	7600.318
8.	7600.756	7600.80	01.96	01.945
9.	02.620	02.64	03.77	03.796
10.	04.708	04.74	05.90	05.871
11.	07.020	07.03	08.21	08.170
12.	09.556	09.54	10.71	10.693
13.	12.316	12.31	13.44	13.440
14.	15.300	15.30	16.39	16.411

First series:
$V = 7593.904$
$L = 35.714$
$c = - 0.357$

Second series:
$V = 7595.195$
$L = 35.715$
$c = - 0.473$

TRAIN OF GREAT A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Computed.
15.	...	...	7621.260	7621.299
16.	7623.590	7623.535	24.765	24.772
17.	27.310	27.310	28.480	28.480
18.	31.255	31.275	32.445	32.413
19.	35.435	35.460	36.59	36.571
20.	39.820	39.840	40.97	40.954
21.	44.440	44.470	45.57	45.562

TRAIN OF GREAT A, *Continued.*

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Compu
22.	49.285	49.305	50.39	50.3
23.	54.355	54.360	55.448	55.4
24.	59.650	59.615	60.715	60.7
25.	65.170	65.148	66.218	66.2
26.	70.915	70.880	71.945	71.9
27.	76.885	76.840	77.89	77.9
28.	83.080	83.025	84.075	84.1
29.	89.500	89.450	90.49	90.5
30.	96.145	96.105	97.13	97.1
31.	7703.015	7703.020	7704.02	04.0
32.	10.110	10.160	11.16	11.1

First series:

$V = 7594.669$
$L = 35.556$
$c = + 0.067$

Second series:

$V = 7596.044$
$L = 35.556$
$c = - 0.04$

SECONDARY TRAIN OF GREAT A.

	FIRST SERIES.		SECOND SERIES.	
	Computed.	Measured.	Measured.	Compu
15.	7622.076	7622.06	...	7623.2
16.	25.613	25.62	7626.79	26.7
17.	29.356	29.36	30.50	30.5
18.	33.305	39.29	34.42	34.4
19.	37.460	37.46	38.57	38.5
20.	41.821	41.81	42.91	42.9
21.	46.388	46.36	47.46	47.4
22.	51.161	51.19	52.24	52.2
23.	56.140	56.14	57.23	57.2

First series:

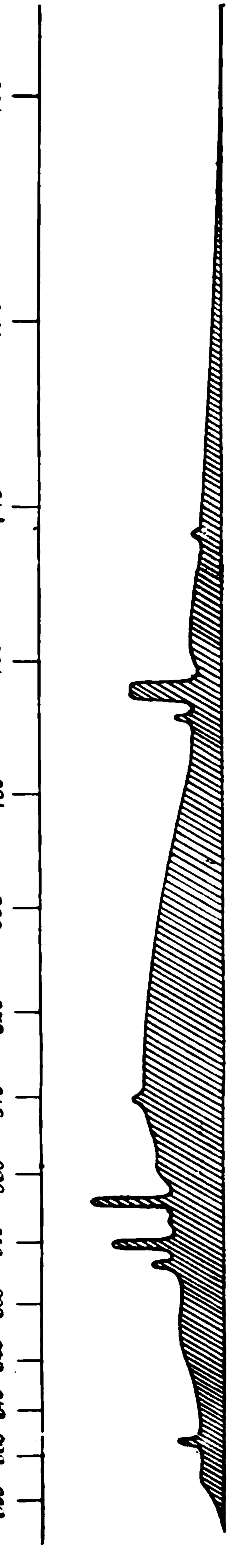
$V = 7593.4535$
$L = 38.835$
$c = + 3.34$

Second series:

$V = 7596.122$
$L = 37.736$
$c = + 2.019$

Sub-group in Head of A following the 1st Series. MEASUREMENTS ONLY.			Fragment of Sub-group in Hea A following the 2nd Series. MEASUREMENTS ONLY		
	Sub-series No. 1.	Sub-series No. 2.		Sub-series No. 3.	Sub-series
5.	7597.00	7598.20*			
6.	98.29	99.45			
7.	99.74	7600.90*			
8.	7601.42	02.57*			
9.	03.25	04.40			
10.	05.36	06.48	10.	7606.48	
11.	07.65	08.83	11.	08.83	7610.1
12.	10.10*d*	11.28	12.	11.45	
13.	12.84	13.98	13.	14.28	
14.	15.78	...	14.	17.25?	

The numbers marked with an * are hypothetical positions.



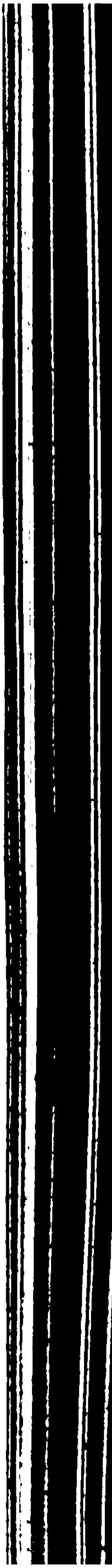
THE SPECTRUM OF γ ARGUS.*

W. W. CAMPBELL.

I have recently undertaken to determine as accurately as possible the positions of the bright lines in the spectra of some of the *Wolf-Rayet* stars. Fifty stars of that type are now known, of which γ Argus, of the 3d magnitude, is the only bright one. When this star is on the meridian of Mt. Hamilton its altitude is less than 6°, and can be observed with the great telescope only a few minutes each evening. Nevertheless I have been able to determine the positions of ten bright lines and bands by visual observations, with as great accuracy as the unfavorable position of the star will permit. The character of the lines is shown in the accompanying intensity curve, and their measured wave-lengths (Rowland's scale) are given in the following table. The continuous spectrum is visible from B to K, being particularly strong in the blue and violet.

The broad band 4651 is strongly suspected to be double with components near 4643 and 4659.

The extremely unfavorable weather prevented me from completing the investigation of the photographic portion of the spectrum, but a few partially successful photographs were obtained. They show many additional bright and dark lines, prominent among which are the bright line at λ 4469 (possibly the chromosphere line at λ 4472), the broad bright lines at λ 433 and λ 427, and *the dark lines* Hγ, Hδ and H. At F the spectrum appears to be strictly continuous. The visual observations show C to be bright.



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[*] Communicated by the author.

[†] Hasty measures, half weight.

Line	1893 Feb. 15	Feb. 17.	Feb. 18.	Feb. 19.	Feb. 20.	Feb. 22.	Feb. 23.	Feb. 27.	Mc 27
	670				673		673		
C	6563.1				6563.8		6567.1		
D_3	5875.8	5873.5	5872.1					5874.9	5874
	5814.1	5813.8	5812.9					5809*	5812
	5694.7	5695.1	5692.8					5693*	5695
								5596	
								5412	
				4689.6	4689.0	4689.0		4688.0	4688
				4651.4	4650.6	4651.2		4650.2	4649
							4440.2	4441.4	4441

A fuller discussion of this interesting spectrum, first o by Respighi at Madras in 1871, is reserved for a futur based upon more data. But I will point out that the lengths of the principal lines assumed by Professor Lock radically different from those obtained by me.

MT. HAMILTON, May 8, 1893.

COMPARISON OF THE INTERNATIONAL METRE WIT WAVE-LENGTH OF THE LIGHT OF CADMIUM.†

ALBERT A. MICHELSON.

The measurement of luminous wave-lengths in metric necessitates two distinct operations: the first is the dete tion of the order of interference produced by a source as homogeneous as possible between rays reflected by two planes; the second is the comparison of the distance betw planes with the metre.

In order to apply this method it is necessary in the firs to produce interference of a very high order and, in the place, to regulate the position of the surfaces with such ex that their distance, even when very great, may be dete with an approximation of a few millionths of a millimet that their parallelism may be verified within a small fracti second.

A preliminary study of the radiations emitted by twenty ent sources has shown that very few exist of such homo that their wave-lengths can be used as absolute stand length.

Most of the sources which correspond to the bright lines

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* *The Meteoric Hypothesis*, pp. 389-391.

† *Comptes rendus*, 17 April, 1893.

ctrum are double, triple or of still more complex constitution; radiations emitted by the vapor of cadmium, however, seem be simple enough to conform with the best conditions.

n all cases when the vapors are produced at atmospheric pres- e, the difference of path of the interfering rays cannot be car- l beyond 2 or 3 centimetres, or 40,000 and 60,000 wave- gths. These figures are very nearly the same as those found M. Fizeau in his celebrated experiments on interference at at difference of path with sodium light.

f the lack of homogeneity of the source which this limit dis- ses is due to frequent collisions of the vibrating molecules ong themselves or with those of the surrounding gas, which vent them from executing freely their natural vibrations, it uld be possible to greatly augment the order of interference by cing the luminous body in a vacuum, in order to diminish the nber of collisions.

'hanks to this arrangement, it has been possible to obtain h a mercury line interferences corresponding to a difference of h of about half a metre, or 850,000 wave-lengths. An exam- tion of the variations in the sharpness of the fringes, as the erence of path increases, shows however that the source is still y complex: it always appears single with the greatest disper- n that it is possible to realize*, while in reality it contains at st six distinct components.†

n examination of the light of cadmium vapor, made from this nt of view, shows that the red line ($\lambda = 0\mu.6439$) is almost ally simple, although a little wider than the components of the en line of mercury. The sharpness of the fringes diminishes ac- ding to an exponential law and disappears when the difference path approaches 25 cm. or 400,000 wave-lengths; for a differ- e of 10 cm., the visibility is about 0.60 of its maximum value. dmium gives in addition three other remarkable lines, green, e and violet; the first two are similarly very simple and give ges almost as easily visible as those of the red line.

'e have thus, for a single substance, three kinds of radiations

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* A good grating, observed with care, permits a faint companion to be dis- uished very near the principal line.

† The method which allows this result to be reached is based on the relation ch exists between the distribution of the light of the source and the *visibility* e of the fringes. The visibility V is given by the equation

$$V_2 = \frac{[\int \varphi(x) \cos 2\pi D x dx]^2 + [\int \varphi(x) \sin 2\pi D x dx]^2}{[\int \varphi(x)\, dx]^2}$$

hich $\varphi(x)$ represents the law of distribution of light in the source and D the rence of path.

which may be examined successively without modifying rangement of the apparatus; the concordance of the which they give for each increase of distance is a very im check on the exactness of the measures.

The apparatus employed to observe these interference ena serves at the same time for the comparison of the ir iate standards among themselves and with the metre; it called the *interferential comparator*. The essential par instrument is composed of a plate of glass with optical and parallel faces and two plane mirrors. The light wh desired to examine falls on a plate of glass, the first su which is thinly silvered, at any incidence—ordinarily at 4 incident pencil divides into two parts, one reflected and t transmitted. The reflected pencil is returned by one of rors and again passes through the glass plate; the oth turned by the second mirror, reflects on the plate and f sent in the same direction. Elementary consideration that this arrangement is equivalent to the superposition pencils, one reflected on the first mirror, the other on th of the second with respect to the mirror. If the distance these two plane surfaces, one of them real and the other is very small, white light may be employed; colored frin then observed, analogous to Newton's rings and situated surfaces themselves. If, on the contrary, the distance i wave-lengths, it is necessary to employ monochromatic li

It will suffice to examine the case in which the surfaces solutely plane and parallel. It is easy to see that the frin then concentric rings; they may thus be observed with th in the principal focal plane of a telescope. Consequentl can succeed in maintaining the absolute parallelism of faces during their motion, the fringes are always distin though the source have a considerable apparent area.

The only difficulty is to determine the order of inte This difficulty may be overcome by a stroboscopic metho on the periodicity of the induction sparks which pro illumination of the vapors, the period of which (by a me easy to construct) contains an exact and very considera ber of alternate maxima and minima of the passing fring

There is another method which seems to me more cert which has already been put in practice in the preliminary ments made by myself in collaboration with Professor this is to employ several standards of intermediate lengt of which is approximately double the preceding. These

s are compared among themselves in a very exact manner by
ecting by direct observation at each operation, the fraction
fringe which exceeds a whole number. The exactness of this
parison is, moreover, controlled by the concordance of the re-
obtained with the three different radiations. We thus suc-
in finding without error the number of fringes and the re-
ning fraction which corresponds to a distance of 10 cm. be-
n the surfaces under known conditions of temperature and
sure.

e comparison of the final 10 cm. standard with the metre is
e by moving this standard a distance equal to its own length,
peration which is repeated ten times; the position and inclin-
n of the surfaces is controlled at each step by observation of
nterference fringes with white light.*

the first and last positions a mark on the standard is com-
d with the two marks on the normal metre by means of
ometer microscopes.†

e International Committee of Weights and Measures has
me the honor to invite me to repeat these experiments in the
ner here indicated at the Pavillon de Breteuil. The necessary
uments, constructed in America for this purpose, were
ght to Paris last July.

eliminary investigations and the adjustment of the various in-
ments occupied all our time until the last of October, when
regular measures were commenced. The observations were
rst made simultaneously by M. Benoît, Director of the Inter-
onal Bureau, and myself; but M. Benoît had a serious illness
he end of the first series and I have since been deprived of his
able aid.

m happy to take this occasion to thank him for all the facil.
which he has kindly placed at my disposal and for the inter
which he has taken in this work. I have at the same time re-
d valuable assistance from MM. Chappuis and Guillaume,
e latter part of the work, and from Mr. F. L. O. Wadsworth,
e construction and installation of the instruments; I take
sure in expressing to them my sincere thanks.

e two series of observations which I have been able to com-

This method of producing *optical contact* offers the advantage that the pos-
and inclination of one of the surfaces may be controlled by the interferences
by the virtual image of the other. There is no danger of displacing the ap-
tus during the observations. It is also possible to attain absolute contact,
h is impossible with real surfaces, and to pass this position in either direction
easure.

In the present experiments this comparison has been made with an auxiliary
e, which in its turn was compared directly with the normal metre.

plete are not yet entirely reduced; but an approximate
tion shows that there does not exist between them a d
of a wave-length in the total distance between the two
marks of the standard metre, which corresponds to an
about $\frac{1}{1500000}$.*

We have thus a means of comparing the fundamental ba
metric system with a natural unit with the same degre
proximation as that which obtains in the comparison
standard metres. This natural unit depends only on the
ties of the vibrating atoms and of the universal ether; it
in all probability, one of the most constant dimensions in
ture.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and othe
properly included in ASTRO-PHYSICS, should be addressed to George E. H
wood Observatory of the University of Chicago, Chicago, U. S. A. A
papers are requested to refer to last page for information in regard t
tions, reprint copies, etc.

The Total Eclipse of April 16.—We learn from *Nature* of April 27 tha
lowing telegram has been received by Lord Kelvin from Professor Thorp
in charge of the English eclipse party in Africa:— "April 19, 1893,
President Royal Society, Burlington House, London. Eclipse succes
served at Fundium. Position good, weather fine, very slight haze. Sli
scope good, but mainly prominence lines; calcium and hydrogen seen
on Moon. Thirty prismatic camera photographs, eighteen excellent
prominence lines; corona lines doubtful. Ten coronograph pictures,
good. Photometric work successful; twenty comparisons with equator
with integrating apparatus. Deslandres and Colculesco also observe
dium, with good results. No word from Bigourdan at Joal. Health
tion good. Blonde leaves for Teneriffe to-morrow.—Thorpe."

The Editor—Astronomy and Astro-Physics—DEAR SIR: In my pa
December No. of ASTRO-PHYSICS—a note on the new spectrum of Nova
883, line 2, the figure 155 $\mu\mu$ is wrongly attributed to Dr. Crew's meas
The interval has apparently been taken by mistake from the Stonyhur
stead of from the observations made at Mount Hamilton. If you will k
a prominent place in your next No. to this apology for an unaccounta
you will greatly oblige the author. WALTER SIDGR

Circular Concerning the Hodgkins Fund Prizes. In Oct., 1891, Thom
Hodgkins, Esq., of Setauket, New York, made a donation to the Smiths
stitution, the income from a part of which was to be devoted "to the in
diffusion of more exact knowledge in regard to the nature and proper
mospheric air in connection with the welfare of man."

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* In the determination of the relative values of the three wave-lengt
ror is only about $\frac{1}{20000000}$.

With the intent of furthering the donor's wishes, the Smithsonian Institution
ow announces the following prizes to be awarded on or after July 1, 1894,
ould satisfactory papers be offered in competition:—

1. A prize of $10,000 for a treatise embodying some new and important discov-
y in regard to the nature or properties of atmospheric air. These properties
ay be considered in their bearing upon any or all of the sciences—*e. g.*, not only
regard to Meteorology, but in connection with hygiene, or with any depart-
ent whatever of biological or physical knowledge.

2. A prize of $2,000 for the most satisfactory essay upon—

(*a*). The known properties of atmospheric air considered in their relationship
research in every department of natural science, and the importance of a study
the atmosphere considered in view of these relationships.

(*b*). The proper direction of future research in connection with the imperfec-
ons of our knowledge of atmospheric air, and of the connections of that know-
lge with other sciences.

The essay, as a whole, should tend to indicate the path best calculated to lead
worthy results in connection with the future administration of the Hodgkins
undation.

3. A prize of $1,000 for the best popular treatise upon atmospheric air, its
operties and relationships (including those to hygiene, physical and mental).

This essay need not exceed 20,000 words in length; it should be written in
nple language, and be suitable for publication for popular instruction.

4. A medal will be established, under the name of THE HODGKINS MEDAL OF
IE SMITHSONIAN INSTITUTION, which will be awarded annnually or biennially, for
portant contributions to our knowledge of the nature and properties of atmos-
eric air, or for practical applications of our existing knowledge of them to the
lfare of man-kind. This medal will be of gold and will be accompanied by a du-
cate impression in silver or bronze.

The treatises may be written in English, French, German or Italian, and
ould be sent to the Secretary of the Smithsonian Institution, Washington, be-
e July 1, 1894, except those in competition for the first prize, the sending of
ich may be delayed until December 31, 1894.

The papers will be examined, and prizes awarded, by a committee to be ap-
inted as follows: One member by the Secretary of the Smithsonian Institution,
e member by the President of the National Academy of Sciences, one by the
esident, *pro tempore*, of the American Association for the Advancement of Sci-
e; and the committee will act together with the Secretary of the Smithsonian
titution as member, *ex officio*. The right is reserved to award no prize, if, in the
lgment of the committee, no contribution is offered of sufficient merit to war-
it an award. An advisory committee of not more than three European men of
ence may be added at the discretion of the Committee of Award.

f no disposition be made of the first prize at the time now announced, the Insti-
ion may continue it until a later date, should it be made evident that impor-
it investigations relative to its object are in progress, the results of which it is
ended to offer in competition for the prize. The Smithsonian Institution reser-
the right to limit or modify the conditions for this prize after December 1,
94, should it be found necessary. Should any of the minor prizes not be award-
to papers sent in before July 1, 1894, the said prizes will be withdrawn from
npetition.

principal motive for offering these prizes is to call attention to the Hodgkins'
d, and the purposes for which it exists, and accordingly this circular is sent
the principal universities and to all learned societies known to the Institu-

tion, as well as to representative men of science in every nation. Suggestion recommendations in regard to the most effective application of this fund a vited.

It is probable that special grants of money may be made to specialists en in original investigation upon atmospheric air and its properties. Applica for grants of this nature should have the endorsement of some recognized emy of sciences, or other institution of learning, and should be accompani evidences of the capacity of the applicant, in the form at least of one m already published by him, based upon original investigation.

To prevent misapprehension of the founders wishes, it is repeated that t coveries or applications proper to be brought to the consideration of the Co tee of Award, may be in the field of any science or any art without restri provided only that they have to do with "the nature and properties of a pheric air in connection with the welfare of man."

Information of any kind desired by persons intending to become compe will be furnished on application.

All communications in regard to the Hodgkins Fund, the Hodgkins the Hodgkins Medals, and the Hodgkins Fund Publications, or applicatio grants of money, should be addressed to S. P. Langley, Secretary of the S sonian Institution, Washington, U. S. A.

S. P. LANGLEY, *Secretary of the Smithsonian Institutio*

Washington, March 31, 1893.

" Asymmetry " of the Concave Gratings.—Dr. Ames writes us that the so asymmetry of a concave grating noticed by Dr. Rydberg in a recent num the *Philosophical Magazine* and in the last number of this journal, is a pe ity very often observed in the gratings used and tested in the Physical La tory of the Johns Hopkins University. The cause is beyond a doubt due slight error made in placing the surface to be ruled under the diamond poin Professor Rowland's new dividing engine, which is approaching completio error will be entirely avoided. In Dr. Ames' paper on the Concave Grating, ence is made to the proper correction for this fault, viz., revolution around tical axis. Dr. Rydberg's theory is thus confirmed in every point.

Selective Absorption of Gratings.—In a recent paper by F. Paschen on " metric Investigations," (*Wied. Ann.*, No. 2, 1893), the question of the se absorption of gratings is for the first time considered. The author finds as sult of a series of most careful experiments that the energy-curves of di gratings have individual peculiarities, depending upon the shape of the g cut by the diamond point. These peculiarities are such as to render the obtained with different gratings entirely uncomparable, and to preclude t sibility of using a grating, either metallic or glass, for absolute measureme intensity.

This dependence of the shape of the energy curve upon the form of gro the grating is entirely in accordance with the theory of gratings, as given re in this magazine by Professor Rowland.

Separation and Striation of Rarefied Gases.—In the *Philosophical Magazi* March, 1893, Mr. E. C. C. Baly gives the results of some most interestin ingenious experiments performed upon the electric discharge through gases finds that when the current is passed through a mixture of two gases, the ponents are separated, one collecting at the negative pole, the other rema hind; and conjectures that this fact may be intimately connected with the dif-rences observed in the spectra of the positive and negative poles. His experi-ents also lead him to think that with a pure gas or vapor there is no striation, most suggestive idea.

Absorption Spectrum of Oxygen.—In his study of these lines in the so-called solar spectrum" which are caused by the absorption of the Earth's atmosphere r. L. E. Jewell has found another series besides the A, B, and α groups which e due to oxygen. This new one is in the region about w. l. 5790. All four ser-s are of marvellous similarity; and there is a most evident law connecting the ries as well as the lines of each series. Mr. Jewell is at present engaged in work-g out these relationships in full.

Correction to Professor Rowland's New Table of Standard Wave-lengths.—A. & -P., April, 1893, p. 337. Last line on page, for 0.050 read 0.150.

Observations of the Aurora.—Lieutenant Peary of the United States Navy, ring his coming expedition to the northern-most Greenland, will record observ-ions of the aurora, upon a plan that will enable comparisons to be made detail with records from other localities. The plan is already in operation, on an international basis, and the results are proving to be important. Num-ous observers widely distributed are desirable, and inasmuch as even those ho have no special technical knowledge may make entries that will be of value, y who feel so disposed may co-operate. Further information and supplies of anks may be obtained from the undersigned, who will be glad to receive also y records of observations of the aurora whatever, for purposes of compari-n.

M. A. VEEDER.

Lyons, New York, U. S. A., April, 1893.

A New Astro-Photometric Method.—Under this title Messrs. Lagrange and roobant describe a form of Stellar photometer which they have invented, and to me extent tested by observation at the Royal Observatory at Brussels. The incipal novelty seems to be the employment of an incandescent electric mp as the source of light for an artificial comparison star, and the control of brightness by measuring with electrical apparatus the intensity of the current ed. Within the ordinary limits of variation the intensity of the light was und by an independent investigation to be nearly a linear function of the elec-omotive force. The brightness of the artificial star is varied (1) by means of iris diaphragm, (2) by introducing in the path of the rays a variable thickness glass, for which purpose two opposed glass wedges can be moved in and out by e observer. For observing colored stars a strip of glass of the proper shade is ced in front of the electric lamp, but it would seem as if this were only shifting e difficulty attending such comparisons to a subsequent investigation, liable to e same errors.

The introduction to Messrs. Lagrange and Stroobant's paper (Bulletin de cadémie royale de Belgique, XXIII, No. 6) gives an excellent résumé of previous struments for determining stellar magnitudes.

The Motion of the Solar System, from the Potsdam Observations.—Dr. P. Kempf the Astro-Physical Observatory of Potsdam, has deduced the amount and di-ction of the motion of the solar system from Professor Vogel's measures of the otions of stars in the line of sight. As only 51 stars were bright enough for

observation the result of Dr. Kempf's reduction is necessarily subject to
certainty, but it is nevertheless of extreme interest from the fact that it is
one based on spectroscopic methods which has yet been obtained. Two
of reduction were employed. Giving all the stars the same weight, and r
them as perfectly independent, the apex of the Sun's way is found to be
206°.1 ± 12°.0, Dec. + 45°.9 ± 9°.2, and the velocity of the Sun's mo
± 1.8 (English) miles per second. As, however, several groups of stars (
in Orion and Ursa Major) have a common motion both in and across
sight, and are thus shown to be physically connected, the above method gi
stars an undue weight, and another reduction, in which each group is c
as a single star, places the apex of the Sun's way in R. A. 159°.7 ± 2
+ 50°.0 ± 14°.3, and gives for the velocity of motion 8.1 ± 2.0 miles.

Professor Vogel regards the observations as insufficient in number
mining the direction of motion with anything like certainty, but thinks
furnish a more satisfactory value of the velocity than that deduced fro
motions with certain assumptions in regard to the distances of the st
suming Struve's result for the direction of the Sun's motion, viz., R. A
Dec. + 31°.0, the velocity deduced from the Potsdam observations is
miles.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR JULY AND AUGUST.

These two months being the most delightful of the year for astr
work, we hope that our readers will not fail to make use of their opport
study the face of the sky. Nearly all of the planets will be visible under
less favorable circumstances during some part of the night. The ri
most brilliant parts of the galaxy will be visible in the early evening.

At 9 o'clock, July 1, the constellation Leo will be low in the west. B
very near the horizon will be found the three planets Mercury, Venus a
Higher up will be Virgo with the golden Saturn in the center of the cons
north of Virgo, the great cluster Coma Berenices, and Bootes with
first magnitude star Arcturus; near the meridian to the south, Libra wit
tle green planet Uranus at its western boundary, ruddy Antares and t
ous claws of Scorpio, the crooked Serpens and Ophiuchus the serpent bea
head the Northern Crown, *Corona Borealis*, and Hercules, containing th
the Solar Way. Towards the east the great arch of the Milky Way exte
south to north with the constellations Sagittarius, Scutum Sobieski, Aq
nus and Lyra. In the morning one may see the constellations Caprico
rius, Pegasus, Cetus, Pisces, Aries, Andromeda, Perseus and Cassiopei
these constellations contain interesting objects which we have not spac
tion here but which are described in most hand books of astronom
may be well seen with telescopes of small aperture, from 3 to 5 in
even an ordinary opera-glass will reveal many wonderful features of th
dome, which may not be so well shown with more powerful instrument

Mercury will be at greatest elongation east from the Sun, 26° 30′,
and will therefore be visible to the naked eye, just after sunset, for se
nings about that time. Mercury will then be about 3° south and
Venus and Mars. Mercury will be at inferior conjunction August 8 and
est elongation west from the Sun, 18° 16′, August 25, when he will be
the morning.

Venus will be the bright "evening star" during these months, acc
during the first days by Mercury and Mars and later by Saturn. On
8^h 02^m A. M. central time Venus will be in conjunction with Mars at an
distance of only 18′ north. On that evening and on the preceding the tw

ay be seen together in the low power fields of small telescopes. It will be inter-
ting to compare their apparent sizes and the color and brilliancy of their disks.

Venus will be in conjunction with the Moon July 14 at 3^h 42^m P. M., 3° 24′
uth, and again Aug. 13 at 5^h P. M. 1° 41′ south. Toward the end of the month
e will approach quite near to Saturn. The disk of Venus will during these
onths be almost fully illuminated, the gibbous phase becoming somewhat no-
eable toward the end of August.

Mars will be low in the west after sunset and, during the first part of July, in
e vicinity of Venus and Mercury as described in the preceding paragraphs. He
not favorably situated for observation. His apparent diameter is now less
an 4″.

Jupiter will be in good position for morning observations. He is over 18°
rth of the equator so that he crosses the meridian at a high altitude. We may
erefore expect that the results of observations of Jupiter's surface will be more
luable than those made during the past three or four years. Jupiter will be at
adrature, 90° west from the Sun, Aug. 22; in conjunction with the Moon July
at noon and again Aug. 5 at 2^h 13^m A. M.

Saturn will be "evening planet" with Venus and Mercury. He has passed
e favorable position for this year but the rings may still be seen during July and
gust. He will be in conjunction with the Moon, a little over a degree north,
ly 18 at 7^h 36^m P. M. and Aug. 15 at 9^h A. M.

Uranus is also "evening planet" but considerably farther east than Saturn.
ring July he will be almost stationary, about 1° east and 30′ south of the fifth
agnitude star λ Virginis. The two, planet and star, are not greatly different in
ightness, but the former may be distinguished by the dull green color of his
ht if not by the clearly defined disk.

Neptune may be observed in the morning. He may be found about 6° north-
st of Aldebaran, between the fifth magnitude stars τ and ι Tauri, 2° west and
′ north of the last. The best way to find him will be to make a chart of all the
rs visible in the space between τ and ι Tauri on several nights and see which
r moves. Neptune during July and August will move about a degree and a
lf or three times the Moon's diameter eastward.

ate.	R. A.	Decl.	Rises.	Transits.	Sets.
893.	h m	° ′	h m	h m	h m
			MERCURY.		
ly 5......	8 49.0	+ 18 23	6 34 A. M.	1 52.9 P. M.	9 12 P. M.
15......	9 26.7	+ 13 42	6 52 "	1 50 2 "	8 48 "
25......	9 37 0	+ 10 27	6 38 "	1 22.1 "	8 06 "
g. 5......	9 16.2	+ 10 44	5 33 "	12 18.1 "	7 03 "
15......	8 52.1	+ 14 05	4 15 "	11 14.7 A. M.	6 14 "
25	9 06.9	+ 16 02	3 42 "	10 50 2 "	5 58 "
			VENUS.		
ly 5......	8 15.4	+ 21 16	5 47 A. M.	1 19.3 P. M.	8 52 P. M.
15......	9 05.8	+ 18 15	6 12 "	1 30.3 "	8 48 "
25......	9 54.1	+ 14 25	6 38 "	1 39.1 "	8 40 "
g. 5......	10 45.0	+ 9 28	7 07 "	1 46.7 "	8 27 "
15......	11 29.8	+ 4 32	7 32 "	1 52.0 "	8 12 "
25......	12 13.7	− 0 36	7 56 "	1 56.5 "	7 57 "
			MARS.		
ly 5......	8 24.7	+ 20 31	6 00 A. M.	1 28.7 P. M.	8 57 P. M.
15......	8 50.7	+ 18 55	5 54 "	1 15.3 "	8 36 "
25......	9 16.2	+ 17 06	5 49 "	1 01.4 "	8 14 "
g. 5......	9 43.7	+ 14 54	5 43 "	12 45.6 "	7 49 "
15	10 08.2	+ 12 42	5 37 "	12 30.6 "	7 24 "
25......	10 32.3	+ 10 22	5 32 "	12 15.4 "	6 59 "
			JUPITER.		
ly 5......	3 23 4	+ 17 36	1 14 A. M.	8 29.0 A. M.	3 44 P. M.
15......	3 31.0	+ 18 03	12 40 "	7 51.1 "	3 15 "
25......	3 37.8	+ 18 26	12 06 "	7 24.6 "	2 44 "
g. 5......	3 45.5	+ 18 50	11 24 P. M.	6 44 5 "	2 06 "
15......	3 50.6	+ 19 04	10 48 "	6 10.0 "	1 32 "
25......	3 54.2	+ 19 15	10 12 "	5 34.5 "	12 57 "

SATURN.

July	5......	12 28.3	− 0 25	11 31 A. M.	5 31.6 P. M.	11 3
	15......	12 30.2	− 0 39	10 54 "	4 54.1 "	10 5
	25......	12 32.6	− 0 58	10 19 "	4 17.2 "	10 1
Aug.	5......	12 35.8	− 1 19	9 40 "	3 37.1 "	9 3
	15......	12 39.1	− 1 43	9 05 "	3 01.1 "	8 5
	25......	12 42.8	− 2 07	8 31 "	2 25.5 "	8 2

URANUS.

July	5......	14 17.9	− 13 20	2 12 P. M.	7 20.8 P. M.	12 3
	15......	14 17.8	− 13 20	1 33 "	6 41.4 "	11 5
	25......	14 18.0	− 13 21	12 54 "	6 02.4 "	11 1
Aug.	5......	14 18.6	− 13 25	12 11 "	5 19.7 "	10 2
	15......	14 19.4	− 13 29	11 34 A. M.	4 41.5 "	9 5
	25......	14 20.8	− 13 36	10 56 "	4 03.2 "	9 1

NEPTUNE.

Date. 1893.		R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Set h
July	5......	4 43.8	+ 20 48	2 18 A. M.	9 48.4 A. M.	5 1
	15......	4 45.2	+ 20 50	1 36 "	9 06.5 "	4 3
	25......	4 46.2	+ 20 52	1 02 "	8 32.3 "	4 0
Aug.	5......	4 47.4	+ 20 54	12 20 "	7 50.1 "	3 2
	15......	4 48.2	+ 20 55	11 41 P. M.	7 11.7 "	2 4
	25......	4 48.9	+ 20 55	11 02 "	6 32.8 "	2 0

THE SUN.

July	5......	7 00.2	+ 22 44	4 23 A. M.	12 04.4 P. M.	7 4
	15.....	7 41.0	+ 21 26	4 31 "	12 05.8 "	7 4
	25......	8 21.0	+ 19 31	4 41 "	12 06.3 "	7 3
Aug.	5......	9 03.8	+ 16 47	4 53 "	12 05 7 "	7 1
	15......	9 41.7	+ 13 50	5 05 "	12 04.2 "	7 0
	25....	.10 18.7	+ 10 31	5 16 "	12 01.8 "	6 4

Mr. Marth's Ephemerides of the Satellites of Saturn.

[From *Monthly Notices*, Jan. 1893.].

In this table the times have been changed from Greenwich Mean Time to Centra
dard Time. The abreviations *Rh.*, *Te.*, *Di.*, *En.*, and *Mi.*, stand for the names of th
lites Rhea, Tethys, Dione, Enceladus, and Mimas. The letters *a*, *b*, *c*, *d*, and *e*, st
conjunctions of the satellites in order as follows: With the preceding end of th
ring; with preceding end of planet's equatorial diameter; with center of planet; w
lowing end of planet's diameter; with following end of ring. The letters *n* and s
that the satellite at the time of conjunction is north or soutn of the point designa
the preceding letter: *Sh.* means that the shadow of a satellite is near the central m
of the planet; *Ecl. D.* and *Ecl. R.*, the disappearance and reappearance of a satellit
ginning and end of an eclipse. The letters e and w standing alone signify easte
western elongations.

June 1893.			June 1893.			June 1893.			June 1983.		
16	2.4 pm	Rh sup		11 0 pm	Te an		5.6 pm	Te an		6 5 pm	Te b
	2.7	Di e		11.2	Di ds		6.1	Mi as		7.5	Di b
	4.3	Rh dn	20	1.5	En as		7.6	Te bn		8.5	Te a
	4.5	Mi en		4 4	Mi es		10 5	Te dn	27	1.5	Di e
	6.9	Rh en		5.3	Di w	24	12.2	Rh w		2.2	Te b
	8.9	En an		9.6	Te es		4.1	En as		5.0	Rh e
17	1.3	En es		10.3	Mi as		4 3	Te es		5.1	Te d
	3.1	Mi en		10.3	Rh an		4.8	Mi as		7 1	Te e
	5.5	Rh e	21	1 5	Di en		6.3	Te ds		7.6	Rh d
	7.7	En as		3 0	Mi es		7.8	Di e		9.5	Rh
	8.5	Mi es		4.0	En es		9.2	Te bs	28	3 8	Te b
	11.6	Di w		8.3	Te an	25	1.3	Rh bn		5.8	Te a
18	2.8	Di bn		8 9	Mi as		1.9	Di bs		10.4	Di w
	4.1	Rh es		10 3	Te bn		2.9	Te an	29	1.2	Di b
	5.6	di dn		10 4	En as		3.3	Rh sup		2.5	Te d
	6.1	Mi es	22	2.7	Di es		4.1	Di as		4.4	Di i
	6.7	Rh ds		2 8	En en		4.9	Te bn		4.5	Te e
	7 8	Di en		4.9	Di ds		5.2	Rh dn		6.6	Di e
	8 6	Rh inf		6.9	Te es		7.7	Rh en	30	1.1	Te b
	10.2	En es		7 5	Mi as		7.8	Te dn		3.1	Te a
	10 5	Rh bs		8.2	Di bs		9.8	Te en		7.8	Di e
19	2.7	En an		8.9	Te ds	26	1.6	Te es		10.0	Di d
	5.7	Mi es		10.4	Di as		3.6	Te ds	July 1893.		
	9.0	Di es	23	1.5	Rh as		5.2	Di an	4	4.2	Rh s
	9.0	Di es		5.4	En an		6.4	Rh e			

Configuration of Jupiter's Satellites at Midnight Central Time.

July	
1	3 2 1 ○ 4
2	3 ○ 1 2 4
3	3 1 ○ 2 4
4	♃ 2 ○ 4 3
5	4 2 ○ 1 3
6	4 1 ○ 2 3
7	4 2 ○ 3 1
8	4 2 3 1 ○
9	4 3 ○ 2 1
10	4 3 1 ○ 2
11	4 2 ○ 1 ●
12	4 2 ○ 3 ●
13	1 ○ 4 2 3
14	♃ ○ 1 3 4
15	2 3 1 ○ 4
16	3 ○ 2 1 4
17	3 1 ○ 2 4
18	2 3 ○ 1 4
19	2 1 ○ 3 4
20	♃ ○ 2 4 3
21	○ 4 2 1 3

July	
22	2 4 1 3 ○
23	4 3 ○ 2 1
24	4 3 1 ○ 2
25	4 2 3 ○ 1
26	4 2 1 ○ 3
27	4 ○ 1 2 3
28	4 ○ 1 2 3
29	2 4 1 3 ○
30	3 ○ 4 1 ●
31	3 1 ○ 2 4
Aug.	
1	3 2 ○ 1 4
2	2 1 ○ 3 4
3	○ 1 2 3 4
4	1 ○ 2 3 4
5	2 1 ○ 3 4
6	3 2 ○ 1 4
7	♃ 3 1 ○ 2
8	♃ 4 3 ○ 1
9	4 2 1 ○ 4
10	4 ○ 2 1 3

Aug.	
11	4 1 ○ 2 3
12	♃ 4 2 ○ 3
13	4 3 2 ○ 1
14	3 4 1 ○ 2
15	3 4 ○ 2 1
16	2 1 ○ 3 4
17	○ 2 1 3 4
18	1 ○ 2 3 4
19	2 ○ 3 4 1
20	3 2 ○ 4 ●
21	3 1 ○ 2 4
22	3 ○ 2 1 4
23	2 1 ○ 4 ●
24	4 ○ 1 3 ●
25	4 1 ○ 2 3
26	4 2 ○ 1 3
27	4 2 3 1 ○
28	4 3 1 ○ 2
29	4 3 ○ 1 2
30	4 2 1 3 ○
31	4 2 ○ 1 3

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A................$0^h\ 52^m\ 32^s$
Decl.................$+81°\ 17'$
Period............$2d\ 11^h 50^m$
1893.

July	2	1 A. M.
	7	1 "
	11	midn.
	16	"
	21	"
	26	11 P. M.
	31	11 "
Aug.	5	11 "
	10	10 "
	15	10 "
	20	10 "
	25	9 "
	30	9 "

ALGOL.

R. A...............$3^h\ 1^m\ 1^s$
Decl................$+ 40°\ 32'$
Period............$2d\ 20^h 49^m$

July	11	5 A. M.
	14	2 "
Aug.	3	3 "
	5	midn.
	23	5 A. M.
	26	2 "
	28	11 P. M.

λ TAURI.

R. A........... ....$3^h\ 54^m\ 35^s$
Decl.................$+ 12°\ 11'$
Period.............$3d\ 22^h 52^m$

July	31	4 A. M.
Aug.	4	3 "
	8	2 "
	12	1 "
	15	midn.

δ LIBRÆ.

R. A.............$14^h\ 55^m\ 06^s$
Decl....... ......$-\ 8°\ 05'$
Period........ ..$2d\ 7^h\ 51^m$

July	2	4 A. M.
	6	8 P. M.
	9	4 A. M.
	13	8 P. M.
	16	3 A. M.
	20	7 P. M.
	23	3 A. M.
	27	7 P. M.
	30	3 A. M.
Aug.	6	2 "
	13	2 "
	20	1 "
	27	1 "

U CORONÆ.

R. A.............$15^h\ 13^m\ 43^s$
Decl...............$+ 32°\ 03'$
Period..........$2d\ 10^h\ 51^m$

July	1	11 P. M.
	8	9 "
Aug.	1	midn.
	8	10 P. M.
	15	8 "

U OPHIUCHI.

R. A.. ....$17^h\ 10^m\ 56^s$
Decl...............$+\ 1°\ 20'$
Period...... ....$0d\ 20^h\ 08^m$

July	5	midn.
	6	8 P. M.
	10	midn.
	11	9 P. M.
	16	2 A. M.
	16	10 P. M.
	21	2 A. M.
	21	11 P. M.
	27	1 A. M.

U OPHIUCHI CONT.

	27	9 P. M.
	31	midn.
Aug.	1	8 P. M.
	6	1 A. M.
	6	9 P. M.
	11	2 A. M.
	11	10 P. M.
	16	2 A. M.
	16	10 P. M.
	21	3 A. M.
	21	11 P. M.
	22	7 P. M.
	26	midn.
	27	8 P. M.

γ CYGNI

R. A..............$20^h\ 47^m\ 40^s$
Decl...............$+\ 34°\ 15'$
Period...........$1d\ 11^h\ 57^m$

July	1	5 A. M.
	4	5 "
	7	5 "
	10	5 "
	13	5 "
	16	4 "
	19	4 "
	22	4 "
	25	4 "
	28	4 "
	31	4 "
Aug.	3	4 "
	6	4 "
	9	4 "
	12	4 "
	15	4 "
	18	4 "
	21	3 "
	24	3 "
	27	3 "
	30	3 "

SATURN.

July	5......12 28.3	− 0 25	11 31 A. M.	5 31.6 P. M.	11 3
	15......12 30.2	− 0 39	10 54 "	4 54.1 "	10 5
	25......12 32.6	− 0 58	10 19 "	4 17.2 "	10 1
Aug.	5......12 35.8	− 1 19	9 40 "	3 37.1 "	9 3
	15......12 39.1	− 1 43	9 05 "	3 01.1 "	8 5
	25......12 42.8	− 2 07	8 31 "	2 25.5 "	8 2

URANUS.

July	5......14 17.9	− 13 20	2 12 P. M.	7 20.8 P. M.	12 3
	15......14 17.8	− 13 20	1 33 "	6 41.4 "	11 5
	25......14 18.0	− 13 21	12 54 "	6 02.4 "	11 1
Aug.	5......14 18.6	− 13 25	12 11 "	5 19.7 "	10 2
	15......14 19.4	− 13 29	11 34 A. M.	4 41.5 "	9 5
	25......14 20.8	− 13 36	10 56 "	4 03.2 "	9 1

NEPTUNE.

Date. 1893.		R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Set h
July	5......	4 43.8	+ 20 48	2 18 A. M.	9 48.4 A. M.	5 1
	15......	4 45.2	+ 20 50	1 36 "	9 06.5 "	4 3
	25......	4 46.2	+ 20 52	1 02 "	8 32.3 "	4 0
Aug.	5......	4 47.4	+ 20 54	12 20 "	7 50.1 "	3 2
	15......	4 48.2	+ 20 55	11 41 P. M.	7 11.7 "	2 4
	25......	4 48.9	+ 20 55	11 02 "	6 32.8 "	2 0

THE SUN.

July	5......	7 00.2	+ 22 44	4 23 A. M.	12 04.4 P. M.	7 4
	15.....	7 41.0	+ 21 26	4 31 "	12 05.8 "	7 4
	25......	8 21.0	+ 19 31	4 41 "	12 06.3 "	7 3
Aug.	5......	9 03.8	+ 16 47	4 53 "	12 05 7 "	7 1
	15......	9 41.7	+ 13 50	5 05 "	12 04.2 "	7 0
	25....	.10 18.7	+ 10 31	5 16 "	12 01.8 "	6 4

Mr. Marth's Ephemerides of the Satellites of Saturn.

[From *Monthly Notices*, Jan. 1893.].

In this table the times have been changed from Greenwich Mean Time to Centra
dard Time. The abreviations *Rh.*, *Te.*, *Di.*, *En.*, and *Mi.* stand for the names of th
lites Rhea, Tethys, Dione, Enceladus and Mimas The letters *a*, *b*, *c*, *d*, and *e*, st
conjunctions of the satellites in order as follows: With the preceding end of th
ring; with preceding end of planet's equatorial diameter; with center of planet; w
lowing end of planet's diameter; with following end of ring. The letters *n* and s
that the satellite at the time of conjunction is north or south of the point designa
the preceding letter: *Sh.* means that the shadow of a satellite is near the central m
of the planet; *Ecl. D.* and *Ecl. R.*, the disappearance and reappearance of a satellit
ginning and end of an eclipse. The letters e and w standing alone signify easter
western elongations.

June 1893.		
16	2.4 pm	Rh sup
	2.7	Di e
	4.3	Rh dn
	4.5	Mi en
	6.9	Rh en
	8.9	En an
17	1.3	En es
	3.1	Mi en
	5.5	Rh e
	7.7	En as
	8.5	Mi es
	11.6	Di w
18	2.3	Di bn
	4.1	Rh es
	5.6	di dn
	6.1	Mi es
	6.7	Rh ds
	7 8	Di en
	8 6	Rh inf
	10.2	En es
	10 5	Rh bs
19	2.7	En an
	5.7	Mi es
	9.0	Di es
	9.0	Di es
June 1893.		
	11 0 pm	Te an
	11.2	Di ds
20	1.5	En as
	4 4	Mi es
	5.3	Di w
	9.6	Te es
	10.3	Mi as
	10.3	Rh an
21	1 5	Di en
	3.0	Mi es
	4.0	En es
	8.3	Te an
	8 9	Mi as
	10 3	Te bn
	10 4	En as
22	2.7	Di es
	2 8	En en
	4.9	Di ds
	6.9	Te es
	7 5	Mi as
	8.2	Di bs
	8.9	Te ds
	10.4	Di as
23	1.5	Rh as
	5.4	En an
June 1893.		
	5.6 pm	Te an
	6.1	Mi as
	7.6	Te bn
	10 5	Te dn
24	12.2	Rh w
	4.1	En as
	4 3	Te es
	4.8	Mi as
	6.3	Te ds
	7.8	Di e
	9.2	Te bs
25	1.3	Rh bn
	1.9	Di bs
	2.9	Te an
	3.3	Rh sup
	4.1	Di as
	4.9	Te bn
	5.2	Rh dn
	7.7	Rh en
	7.8	Te dn
	9.8	Te en
26	1.6	Te es
	3.6	Te ds
	5.2	Di an
	6.4	Rh e
June 1983.		
	6 5 pm	Te b
	7.5	Di b
	8.5	Te a
27	1.5	Di e
	2.2	Te b
	5.0	Rh e
	5.1	Te d
	7 1	Te e
	7 6	Rh d
	9.5	Rh
28	3 8	Te b
	5.8	Te a
	10.4	Di w
29	1.2	Di b
	2.5	Te d
	4 4	Di d
	4.5	Te e
	6.6	Di en
30	1.1	Te b
	3.1	Te a
	7.8	Di e
	10.0	Di d
July 1893.		
4	4.2	Rh

Configuration of Jupiter's Satellites at Midnight Central Time.

July		July		Aug.	
1	3 2 1 ○ 4	22	2 4 1 3 ○	11	4 1 ○ 2 3
2	3 ○ 1 2 4	23	4 3 ○ 2 1	12	♃ 4 2 ○ 3
3	3 1 ○ 2 4	24	4 3 1 ○ 2	13	4 3 2 ○ 1
4	♃ 2 ○ 4 3	25	4 2 3 ○ 1	14	3 4 1 ○ 2
5	4 2 ○ 1 3	26	4 2 1 ○ 3	15	3 4 ○ 2 1
6	4 1 ○ 2 3	27	4 ○ 1 2 3	16	2 1 ○ 3 4
7	4 2 ○ 3 1	28	4 ○ 1 2 3	17	○ 2 1 3 4
8	4 2 3 1 ○	29	2 4 1 3 ○	18	1 ○ 2 3 4
9	4 3 ○ 2 1	30	3 ○ 4 1 ●	19	2 ○ 3 4 1
10	4 3 1 ○ 2	31	3 1 ○ 2 4	20	3 2 ○ 4 ●
11	4 2 ○ 1 ●	Aug.		21	3 1 ○ 2 4
12	4 2 ○ 3 ●	1	3 2 ○ 1 4	22	3 ○ 2 1 4
13	1 ○ 4 2 3	2	2 1 ○ 3 4	23	2 1 ○ 4 ●
14	♃ ○ 1 3 4	3	○ 1 2 3 4	24	4 ○ 1 3 ●
15	2 3 1 ○ 4	4	1 ○ 2 3 4	25	4 1 ○ 2 3
16	3 ○ 2 1 4	5	2 1 ○ 3 4	26	4 2 ○ 1 3
17	3 1 ○ 2 4	6	3 2 ○ 1 4	27	4 2 3 1 ○
18	2 3 ○ 1 4	7	♃ 3 1 ○ 2	28	4 3 1 ○ 2
19	2 1 ○ 3 4	8	♃ 4 3 ○ 1	29	4 3 ○ 1 2
20	♃ ○ 2 4 3	9	4 2 1 ○ 4	30	4 2 1 3 ○
21	○ 4 2 1 3	10	4 ○ 2 1 3	31	4 2 ○ 1 3

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A................0^h 52^m 32^s
Decl.................+81° 17′
Period............2*d* 11^h 50^m
1893.

July	2	1 A. M.
	7	1 “
	11	midn.
	16	“
	21	“
	26	11 P. M.
	31	11 “
Aug.	5	11 “
	10	10 “
	15	10 “
	20	10 “
	25	9 “
	30	9 “

ALGOL.

R. A...............3^h 1^m 1^s
Decl.................+ 40° 32′
Period............2*d* 20^h 49^m

July	11	5 A. M.
	14	2 “
Aug.	3	3 “
	5	midn.
	23	5 A. M.
	26	2 “
	28	11 P. M.

λ TAURI.

R. A.......... ....3^h 54^m 35^s
Decl.................+ 12° 11′
Period............3*d* 22^h 52^m

July	31	4 A. M.
Aug.	4	3 “
	8	2 “
	12	1 “
	15	midn.

δ LIBRÆ.

R. A.............14^h 55^m 06^s
Decl....... ......— 8° 05′
Period........ ..2*d* 7^h 51^m

July	2	4 A. M.
	6	8 P. M.
	9	4 A. M.
	13	8 P. M.
	16	3 A. M.
	20	7 P. M.
	23	3 A. M.
	27	7 P. M.
	30	3 A. M.
Aug.	6	2 “
	13	2 “
	20	1 “
	27	1 “

U CORONÆ.

R. A.............15^h 13^m 43^s
Decl...............+ 32° 03′
Period..........2*d* 10^h 51^m

July	1	11 P. M.
	8	9 “
Aug.	1	midn.
	8	10 P. M.
	15	8 “

U OPHIUCHI.

R. A.. ....17^h 10^m 56^s
Decl..............+ 1° 20′
Period...... ....0*d* 20^h 08^m

July	5	midn.
	6	8 P. M.
	10	midn.
	11	9 P. M.
	16	2 A. M.
	16	10 P. M.
	21	2 A. M.
	21	11 P. M.
	27	1 A. M.

U OPHIUCHI CONT.

	27	9 P. M.
	31	midn.
Aug.	1	8 P. M.
	6	1 A. M.
	6	9 P. M.
	11	2 A. M.
	11	10 P. M.
	16	2 A. M.
	16	10 P. M.
	21	3 A. M.
	21	11 P. M.
	22	7 P. M.
	26	midn.
	27	8 P. M.

γ CYGNI

R. A.............20^h 47^m 40^s
Decl...............+ 34° 15′
Period...........1*d* 11^h 57^m

July	1	5 A. M.
	4	5 “
	7	5 “
	10	5 “
	13	5 “
	16	4 “
	19	4 “
	22	4 “
	25	4 “
	28	4 “
	31	4 “
Aug.	3	4 “
	6	4 “
	9	4 “
	12	4 “
	15	4 “
	18	4 “
	21	3 “
	24	3 “
	27	3 “
	30	3 “

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h	m	Angle f'm N pt. °	EMERSION Washington M. T. h	m	Angle f'm N pt. °	Du h
July 6	B.A.C. 410	6.0	13	16	54	14	17	240	1
8	54 Arietis	6.3	12	38	62	13	34	241	0
23	α Scorpii	1.4	8	28	166	9	19	232	0
24	43 Ophiuchi	5.8	8	38	79	10	07	300	1
Aug. 2	e Piscium	5.5	11	55	97	12	44	192	0
3	B.A.C. 609	6.0	12	45	33	13	44	259	0
4	π Arietis	5.7	11	13	35	11	58	271	0
4	ρ^2 Arietis	6.0	14	20	32	15	20	262	1
4	ρ^3 Arietis	6.0	14	24	110	15	05	184	0
5	B.A.C. 1189	6.0	12	31	97	14	16	214	1
16	86 Virginis	5.9	6	58	112	8	12	306	1
23	ω Sagittarii	5.1	13	39	10	14	15	305	0
25	38 Capricorni	6.9	8	40	100	9	48	208	1
25	37 Capricorni	6.0	8	42	63	10	06	245	1
25	$\varkappa$ Capricorni	5.0	14	30	47	15	35	248	1
27	φ^1 Aquarii	4.1	10	01	102	10	54	186	0
28	27 Piscium	5.1	7	02	107	7	43	198	0
28	29 Piscium	5.0	8	40	82	9	40	213	1
28	B.A.C. 8351	8.0	9	02	39	10	05	255	1
31	36 Arietis	6.5	15	53	38	17	08	257	1

Phenomena of Jupiter's Satellites.

	h	m			
July 4	2	35	A. M.	I	Ec. Dis.
5	12	54	"	I	Tr. In.
	2	02	P. M.	I	Sh. Eg.
	3	06	"	I	Tr. Eg.
6	1	23	A. M.	II	Ec. Dis.
12	1	17	"	III	Oc. Re.
	1	45	"	I	Sh. In.
	2	53	"	I	Tr. In.
13	2	16	"	I	Oc. Re.
15	12	38	"	II	Sh. Eg.
	12	41	"	II	Tr. In.
	3	00	"	II	Tr. Eg.
19	12	33	"	III	Ec. Re.
20	12	51	"	I	Ec. Dis.
21	1	32	"	I	Tr. Eg.
22	12	51	"	II	Sh. In.
	3	12	"	II	Sh. Eg.
	3	23	"	II	Tr. Eg.
24	12	46	"	II	Oc. Re.
26	3	05	"	III	Ec. Dis.
27	2	45	"	I	Ec. Dis.
28	1	19	"	I	Tr. In.
	2	14	"	I	Sh. Eg.
29	12	40	"	I	Oc. Re.
	3	26	"	II	Sh. In.
31	12	47	"	II	Ec. Re.
	1	10	"	II	Oc. Dis.
Aug. 4	1	56	A. M.	I	Sh. In.
	3	16	"	I	Tr. In.
5	2	37	"	I	Oc. Re.
	10	30	P. M.	I	Sh. Eg.
	10	55	"	III	Sh. Eg.
	11	57	"	I	Tr. Eg.
6	2	42	A. M.	III	Tr. In.
7	1	09	"	II	Ec. Dis.
	3	24	"	II	Ec. Re.
	3	51	"	II	Oc. Dis.
9	12	22	"	II	Tr.
12	1	01	"	I	Ec.
	11	40	P. M.	I	Tr.
13	12	30	A. M.	I	Sh.
	1	12	"	III	Sh.
	1	52	"	I	Tr.
	2	55	"	III	Sh.
14	3	46	"	II	Ec.
16	12	14	"	II	Sh.
	12	41	"	II	Tr.
	2	58	"	II	Tr.
19	2	55	"	I	Ec.
20	12	12	"	I	Sh.
	1	35	"	I	Tr.
	2	24	"	I	Sh.
	3	47	"	I	Tr.
21	12	55	"	I	Oc.
	10	15	P. M.	I	Tr.
23	12	29	A. M.	II	Sh.
	2	49	"	II	Sh.
	3	17	"	II	Tr.
24	12	42	"	III	Oc.
	2	08	"	III	Oc.
	9	54	P. M.	II	Ec.
	10	25	"	II	Oc.
25	12	42	A. M.	II	Oc.
27	2	06	"	I	Sh.
	3	29	"	I	Tr.
	11	17	P. M.	I	Ec.
28	2	49	A. M.	I	Oc.
	9	57	P. M.	I	Tr.
	10	47	"	I	Sh.
29	12	08	A. M.	I	Tr.
30	3	04	"	II	Sh.
	11	06	P. M.	III	Ec.
31	12	34	A. M.	III	Ec.
	10	15	P. M.	II	Ec.

Phases and Aspects of the Moon.

		d	h m	
Last Quarter	July	6	4 06	P. M.
Perigee	"	11	5 30	"
New Moon	"	13	6 47	A. M.
First Quarter	"	20	11 02	"
Apogee	"	23	8 12	P. M.
Full Moon	"	28	2 10	"
Last Quarter	Aug.	4	10 23	"
Perigee	"	8	3 42	"
New Moon	"	11	2 48	"
First Quarter	"	19	3 52	A. M.
Apogee	"	20	1 00	P. M.
Full Moon	"	27	2 43	A. M.

Ephemeris of Comet 1892 VI (Brooks Aug. 28).

(from *Astr. Nach.* No. 3162).

erlin Midn.		R. A. h			Decl.		log *r*	log *Δ*	Br.
une	9	17	37	06	− 24	43.2	0.4236	0.2148	1.21
	13		31	46	24	08.2	0.4313	0.2262	1.11
	17		26	45	23	34.3	0.4389	0.2387	1.01
	21		22	07	23	01.8	0.4462	0.2520	0.92
	25		17	53	22	31.1	0.4535	0.2658	0.84
	29		14	07	22	01.7	0.4606	0.2805	0.76
uly	3		10	46	21	34.5	0.4675	0.2954	0.68
	7		07	52	21	09.6	0.4743	0.3107	0.62
	11		05	26	20	46.5	0.4810	0.3264	0.56
	15		03	26	20	25.6	0.4875	0.3421	0.50
	19		01	52	20	06.6	0.4939	0.3580	0.45
	23	17	00	44	19	49.6	0.5002	0.3739	0.41
	27	16	59	58	19	34.5	0.5064	0.3897	0.37
	31		59	35	19	21.0	0.5125	0.4055	0.33
ug.	4		59	33	19	09.4	0.5185	0.4210	0.30
	8	16	59	50	18	58.9	0.5243	0.4364	0.27
	12	17	00	27	− 18	50.1	0.5301	0.4515	0.25

Ephemeris of Comet 1893 I (Brooks 1892 Nov. 19).

(from *Astr. Nachr.* 3162).

erlin Midn.		R. A.			Decl.		log *r*	log *Δ*	Br.
une	9	1	35	34	+ 11	03.7	0.3996	0.4749	0.101
	13		35	41	10	34.8	0.4073	0.4714	0.099
	17		35	33	10	04.1	0.4148	0.4673	0.098
	21		35	07	9	31.0	0.4221	0.4629	0.097
	25		34	22	8	55.6	0.4293	0.4580	0.096
	29		33	19	8	17.5	0.4364	0.4528	0.095
uly	3		31	55	7	36.5	0.4434	0.4474	0.094
	7		30	09	6	54.4	0.4502	0.4417	0.094
	11		28	01	6	05.1	0.4569	0.4358	0.093
	15		25	29	5	14.4	0.4635	0.4299	0.093
	19		22	31	4	20.2	0.4700	0.4240	0.093
	23		19	08	3	22.2	0.4764	0.4183	0.092
	27		15	18	2	20.7	0.4826	0.4127	0.092
	31		11	02	1	15.6	0.4888	0.4076	0.092
ug.	4		06	19	+ 0	07.1	0.4949	0.4029	0.001
	8	1	01	10	− 1	04.6	0.5008	0.3988	0.090
	12	0	55	31	− 2	19.3	0.5067	0.3955	0.089

Reappearance of Finlay's Periodic Comet.—Mr. Finlay at the Cape of Good
pe rediscovered on May 17 the comet which was originally discovered by him
886. The position of the comet as determined May 18.6262 was R. A. 23^h
$31^s.2$; Decl. — 5° 01′ 50″, which agrees, within + 7^m in R. A. and + 12′ in
l., with the ephemeris calculated by Schulhof, published in our April and May
nbers. The comet is described as circular, 1′ in diameter, 11 magnitude, very
use, with no tail.

NEWS AND NOTES.

Our readers will please remember that this publication will not appe Next issue will be for August.

Astronomical Spectroscopy is to be the name of the translation of Dr. Spectral-Analyse der Gestirne, now being made by Professor Frost. will appear about Nov. 1, 1893, and its price will be five dollars.

E. E. Barnard's European Visit.—On the morning of May 20, E. E. and wife sailed from New York for Liverpool on the Aurania, Cunard Barnard has been granted a year's vacation from Lick Observatory, an plan to visit the Observatories of England, Scotland, Ireland, France many. We know he will meet everywhere, on the other side of the wat hearty welcome, for there is not an astronomer in foreign lands who know of him by reputation, young as he is, and the cordial greeting i him from scientists there will be a deserved recognition of merit whi nobly earned in the science he so ardently loves and has already s honored. He promises to remember us with communications in his abse

Astronomy Popularized in America.—There seems to be no doubt that est taken in astronomy in America is rapidly on the increase, and the d large telescopes there have played no small part in helping to stir up minds the desire for enlightenment in this fascinating science. Increa number of students and amateurs, and rapidly growing demands for s scopes are signs that can not be misconstrued, indicating as they do interest that even to-day is shown in the oldest of sciences. To sa further these favorable omens, or, in other words, to bring those who ca into closer relations with those who are to be instructed, the editors o OMY AND ASTRO-PHYSICS propose, assuming they get a sufficient numb scribers, to issue a publication entitled "Popular Astronomy." The id project is that it should serve as a guide for self-instruction, and supp ium for queries and answers for methods of work, facts, books, etc. pose to commence with a series of topics for observation, the stars, moo etc., assuming that the readers are supplied only with an opera glass telescope. It is to be in no sense professional "except to be accurate in of fact and principle without being technical in terms." The first numb ready by September of this year if the subscribers are forthcoming.—*Na* land,) May 4, 1893.

Photometric Observations of the Brightness of the Asteroids.—The Har lege Observatory will soon publish Henry M. Parkhurst's Photometric tions of Asteroids and Variable Stars. This valuable work will consist of of observations and tables of reduction, and will give the results of t observations made by Mr. Parkhurst at his home in Brooklyn, N. 9-inch Fitz refractor. The light of 36 of the asteroids, ranging from t the 13th magnitudes, has repeatedly been observed by him during period.

In the earlier observations Mr. Parkhurst thought there was evide or two cases, of a variation of the light of an asteroid which might axial rotation and it was hoped that the rotation of these little bod s be detected. His more extended work, however, does not verify this, as e of the asteroids show any such discordances in the more refined observa- ns. None of them have shown any variation in their light and their rotations not therefore be photometrically determined. The observations are made by method of light extinction: the image of the object being observed to disap- r through a medium of gradually increasing density, a photometric wedge. ndard comparison stars were observed at the same time, and every precaution en to eliminate all errors of observation. The observed magnitude of the as- id is corrected for deficient illumination, for phase, etc., being reduced to dis- e unity from the Earth and the Sun. Observations of the same asteroids ex- ding over many years and thus reduced to a constant distance, are strikingly ordant.

As these observations extend over some ten years they also show that there been no variation in the brightness of the Sun during that time amounting as much as one per cent, or it would have been detected in the work. Mr. khurst finds also that all sides of the Sun give out essentially the same ount of light.

He finds that the light of the asteroids is far more constant than that of the rs. According to his observations an asteroid is twice more reliable, as a con- nt of comparison, than any fixed star. As early as 1860 he had come to the clusion that every star in the sky was more or less variable, and this seems to verified by his observations. This therefore makes the asteroids the most re- le constants for light comparison. But this one important value of these le bodies cannot now be utilized, as the ephemerides of most of them have n discontinued.

The Yerkes' Telescope.—The following facts about the 40-inch Chicago tele- pe have been obtained from Messrs. Warner & Swasey who are building the at tube pier and clock-work.

The pier or column is made in five sections. The base section weighs about tons, the other sections weighing about 5½ tons each. The height of the mn, from base to top is 31 feet 4 inches. Each section of the pier is above feet high.

The head of the pier is of cast iron, in one piece and weighs 5½ tons. The al weight of the pier and head is about 45 tons. The height from the base of pier to the center of motion is 43 feet 6 inches.

The polar axis is made of steel 15 inches in diameter, 13 feet long and weighs ut 3½ tons. The declination axis is made of steel 12 inches in diameter l weighs about 1¾ tons.

The tube is of sheet steel and its total length 62½ feet exclusive of eye-end. largest diameter in the center, is 52 inches. It is 38 inches in diameter at end, and 43 inches at object-glass end. The complete tube will weigh about 6 s. The focal length of the objective is to be about 64 feet

The clock will weigh about 1½ tons and is wound either by hand or by elec- motor.

All quick or slow motion and clamps for right ascension and declination are rated by hand and electricity, from floor, from eye-end and from balcony.

The total weight of the telescope will be about 75 tons.

To give an idea of the immense size of this instrument when the telescope is nted to the zenith the object-glass will be 72 feet up in the air, or about as h as a seven story house.

It is to have an elevating floor like that of the Lick Observatory.

In the *Comptes Rendus* for March 27th and April 4th of this year Mr.
of the Paris Observatory has two important articles. In them he disc
zero-points of the photographic catalogue plate whose centre is at $10^h 52$
and shows that the best results are obtained by connecting it with the fo
which have a corner at its centre. Without these connections the positio
stars on the central plate would be less accurate than the photographic
demands; and we may say that with them the accuracy attained (a
error of about ± 0″.15 in both co-ordinates combined, at the very cent
near the edges) could be readily improved by new observations of the sa
Taking into account all previous available catalogues the probable erro
star's place does not amount to less than ± 0″.5 in either co-ordinate.
now perfectly easy to make this as small as ± 0″.2 by four observations
star, we see that a considerable diminution of the p. e. of the zer
is possible. Fortunately the many meridian observations which this in
accuracy requires can be deferred for the present; and I suggest that
meridian observers who have the instruments and time necessary shal
gate, during the next few years, the question of the accuracy attainable,
of various magnitudes and in various parts of the heavens, by a com
of old and new observations, making such as are necessary. Studies of
are entirely essential if the waste of labor, which has always been a f
meridian observations in most places, shall be prevented for the future.

My own project of observing the positions of all standard polars,
bining with them the results of previous observations fits very well
scheme of operations; but of this more bye-and-bye. T. H. SAF

Mr. Parkhurst's Discovery of Donati's Comet—It was June 2d, 1858 tha
discovered at Florence, the comet which has made his name famous. It
a very faint telescopic object, and not until the latter part of August did
to attain that naked eye visibility which has made it classical.

Before Donati's discovery was known in America, Mr. Parkhurst acc
discovered it on June 29th, while sweeping for Comet IV, 1858. He wa
ing for Comet IV with a 6-inch refracting telescope and found in the pro
tion a faint tailless comet which he assumed was the one which he was
of. Observations soon showed, however, that the object must be a ne
as its motion was at right angles to that of IV. He did not learn for so
that he had been anticipated by another, in finding one of the most
comets on record. Looking at Mr. Parkhurst with his long white
beard and with his gentle face one can not repress the wish that he had
anticipated in the discovery of this beautiful comet.

Mr. Parkhurst still has the six-inch telescope with which he found
comet. The tube is unmounted and stands in a corner of his Observato
not known who made the glass, which was so poor in definition that it
figured by the elder Fitz.

The Lick Telescope Disturbed by Wind. Refering to the note by
Holden in the May number of this journal, on the matter of protecting
telescope from the wind, I desire to say that I suggested the plan of cutti
wind from the instrument by closing the lower half of the slit with canv
after I commenced to work with the 36-inch. Most of my work with t
meter, except on stars very far south, was done with the objects at an al
not less than 40°, and if the vibration of the telescope due to the wind
through this part of the opening could be avoided, the remaining effect

aratively unimportant. The loss of time due to this disturbance was no
ng matter. It is impossible to do any good work with the micrometer while
elescope is shaking. The only thing to do was to turn the dome in some
direction; and frequently in a high wind, even when the shutter was in an
site quarter, the disturbance of the instrument was very annoying. In some
work done there, with the spectrograph for instance, this vibration was of
rious consequence. I never lost faith in the practical value of the device sug-
d, and never saw the time during my stay at Mt. Hamilton when I did not
to do more double star work than I did, or could do under the circum-
es. Certainly Professor Holden in saying that finally I did not care to have
mprovement made on my account is an error, and he has probaby confused
ith some one else in repect to this matter. As a matter of fact I was not
e that the rods referred to had been attached, but as my work in the dome
entirely at night, they might have easily escaped my notice.

hicago, May 20. S. W. BURNHAM.

Vind at the Lick Observatory. I was very much surprised in reading the note
the director of Lick Observatory in the May number concerning certain ex-
ients that had been commenced at the Lick Observatory to provide means
ducing the effect of the wind upon the 36-inch telescope.

had never heard of any such experiments and this is the first intimation
I ever had that such had ever been tried. I had never heard of the exist-
of the "rods," etc., which had been attached to the slit for the purpose of
ucting such experiments.

t is to be regretted that these experiments were not reduced to practice, as it
tirely too important a matter to have been neglected.

regret that my attention was not directed to the existence of these rods, etc.,
at an effort on my part might have been made to test the efficiency of some
of screen to close the lower part of the slit, and to protect the telescope from
vind. E. E. BARNARD.

ew York, May 16, 1893.

hotographs of the Broadening of the Lines in Sun-spot Spectra.—Professor
g and his assistant, Mr. Reed, have been experimenting with isochromatic
s in photographing Sun-spot spectra with the 23-inch. They have secured
very satisfactory negatives which clearly show the unmistakable broaden-
f the Fraunhofer lines in the Sun-spot spectra. Their most successful results
been obtained in the red region of the spectrum.

he Last Observations of the 5th Satellite of Jupiter.—The last observations of
object that were obtained at the Lick Observatory with the 36-in. were on
ary 5th and 8th, 1893, at which times it was seen at western elongation and
ibed as extremely faint. It was then closely following the ephemeris com-
l for it by Mr. Marth. Professor Young with the 23-inch at Princeton ob-
d it last on December 30th 1892. He saw it at eastern elongation at 6 P. M.
e observations at Mt. Hamilton the planet was over two hours further west
e meridian than when observed at Princeton, which would in the main ac-
t for its greater faintness with the 36-inch.

rofessor H. S. Prichett of Washington University, St. Louis is making a
ough discussion of the orbit of the satellite from which many interesting
will be developed.

ome valuable observations were also obtained of it by Mr. Brown with the
. at Washington before its removal. These observations have not yet been
ished.

he following are the results of the measures of the satellite made with the
. at the Lick Observatory:

istance from centre of Jupiter, (reduced to distance 5.20).

rom measures at east elongation 48″.09 ± 0″.06 (14 nights).

rom " " west " 47 .62 ± 0 .18 (7 nights).

hese would correspond relatively to the following distances from the center
piter:

When east of the planet 112500 ± 140 miles.
When west of the " 111410 ± 410 "
Thus indicating some excentricity to the orbit.

From the observations the periodic time is $11^h\ 57^m\ 23^s.1$ and the mo
the satellite in its orbit about 16.4 miles a second.

During the measures of the satellite the diameters of Jupiter were fre
measured. These observations were made through smoked mica and are
lows—the measures being reduced to distance 5.20.

Equatorial diameter 38″.38 ± 0″.03 (20 nights).
Polar diameter 36 .03 ± 0 .05 (14 nights).

These would correspond to the following

Equatorial diameter 89709 ± 65 miles.
Polar diameter 84300 ± 80 miles.

These values are in close accordance with the best filar micrometer mea
the diameters of Jupiter. Except the polar diameter, perhaps, which is som
greater than other determinations. Heliometer measures of the diamete
piter are uniformly about 1″ less than the values obtained with the micr

The satellite is therefore about 67000 miles distant from the surface of

The angular hourly motion of the 5th satellite is about 30°.11. Thou
is much smaller than that of Phobos, the inner satellite of Mars, yet the
velocity in its orbit is some 12 times as great as that of Phobos.

Though the older satellites of Jupiter are readily expanded into small
discs with comparatively small telescopes, the new one has never appeared
than a point of light under the best conditions with the 36-inch. It has b
possible to detect a trace of its shadow when it should be in transit acr
piter's disc. Until better material is at hand the satellite is assumed to be
13th magnitude and not far from 100 miles in diameter.

Removal of the Warner Observatory.—It has been for sometime the in
of Dr. Lewis Swift to remove his telescope from Rochester to a more fav
climate. The increase of electric lights and smoke from the city and the no
cloudiness of Rochester, have all combined in late years to make observat
faint objects, such as Dr. Swift is interested in, all but impossible. The lo
for the rebuilding of this Observatory has at last been decided upon, and
struments and library are already packed and the removal will begin i
ately.

The Observatory is to be removed to the State University at Boulder
rado, and Dr. Lewis Swift and his son Edward are to become connecte
the astronomical department of the University with suitable salaries.

As the 16-inch possesses a fine Clark filar micrometer, with Burnham's
ination, it might be suggested that the most important piece of work tha
be undertaken just now with the instrument in its new position would be
ful series of micrometer measures of the 1,000 odd nebulæ discovered by S
the past ten years. This would be a very valuable contribution to astr
and is a piece of work that might well be undertaken by the younger Swift

Though the Observatory was the property of Mr. Warner, the 16-inc
scope is the personal property of Dr. Swift, being a present to him by the
of Rochester.

Proposed Change in Reckoning the Beginning of the Astronomical Day.—T
tronomical and Physical Society of Toronto, co-operating with the Canad
stitute, of Toronto, an older body already identified with reforms in Time
oning, is distributing to every astronomer, whose address can be obtained
cular letter having for its object the obtaining of a consensus of opinion
subject of the Sixth Resolution of the Washington International Confer
1884, which was carried unanimously by the representatives of the twen
nations there assembled, counting among them several astronomers of
wide fame. This resolution was as follows: "The Conference expresses th
that, as soon as practicable, the Astronomical and Nautical Days will
anged everywhere to begin at Mean Midnight." The circular letter is a
phlet of twelve pages, and includes the report of a joint committee, of wh
Sandford Fleming, is Chairman, and the opinions, for and against the c
tained in the writings of Sir John Herschell, M. Otto Struve, Mr. Christie, t
tronomer Royal, Professor Newcomb, the late Commodore Franklin, Mr. C

mael, F. R. A. S., and Mr. Arthur Harvey, the last two being the Presidents
e societies issuing the circular. The report of the Joint Committee states
if any action is to be taken on the resolution, the most appropriate day for
ew reckoning to take effect would be the first day of the new Century and
as the ephemerides are usually prepared four or five years in advance, a com-
understanding should not be delayed beyond 1895 or 1896, and suggests
answers be secured to the following question: "Is it desirable, all interests
dered, that on and after the first day of January, 1901, the Astronomical
should everywhere begin at Mean Midnight?" The two societies in Toronto
arranged to receive replies to this question and will, in the most impartial
ier, collate them and cause them to be published in a report, a copy of which
e sent to every one who sends in an answer. It is presumed that this re-
will be a valuable one and one full of interest to scientific men the world
Categorical replies will be received, but anyone, desiring to do so, may
reasons for his views. Great difficulty has been met with in procuring even
tial list of observers and others; in fact, some months' delay in issuing the
iar has been caused by this. As it is, the Joint Committee is in possession of
by no means full and complete. For this reason, many astronomers, chiefly
eurs whose opinions are very desirable, may not receive the circular; this
be regarded as accidental, not as intentional. Any scientific man who has
ctical interest in the subject, may obtain a copy of the pamphlet if he send
ame and address to Mr. G. E. Lumsden, corresponding secretary of the As-
omical Society, Toronto. It is to be hoped that this circular will be received
he question answered by everyone in the spirit which animates the societies
ng it. Those bodies only wish to serve the interests of science and, if the con-
s of opinion be in its favor, to do something in moving the world to take
ntage of that which, to them, appears to be the most opportune date for
ng the change suggested. Anyone wishing to send in an answer to the
e question, may address it to The Joint Committee on Astronomical Time.
dian Institute, Toronto, Canada.

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altimore Astronomical Society.—The seventh regular meeting of the Balti-
Astronomical Society, section of the Maryland Academy of Sciences, was
May 9th. Mr. Gildersleeve in the chair. Mr. Pitts exhibited a model illus-
ng the stationary point and retrograde motion of planets in their orbits.
. Stahn, Secretary of Society gave a lecture on Astronomy using lantern
s furnished by Mr. J. Patten, the stereopticon being provided by Mr. J. Pitts.
owing the lecture some time was used in giving instruction in astronomy
Lockyer's text-book. Meetings of the society occur regularly on the 2nd
day of each month.

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he Astronomical and Physical Society of Toronto.—The meeting of this Society
e 18th of April, was held in the Physical Science Rooms of the University of
nto in order that Mr. C. A. Chant, B. A., Lecturer on Physics, might read a
r, with experiments, on The Polarization of Light. There was a large at-
ance of members and of the general public. Mr. Chant was very successful
received the warm commendations of Mr. Charles Carpmael, F. R. A. S., Pres-
of the Society, Mr. John A. Paterson, M. A., Mr. A. Elvins and others. At
neeting on the 2nd of May, five active members were elected, the constitution
e Society was amended and consolidated; solar, planetary, stellar and other
vations were reported; and it was announced that the Third Annual Report
d appear in a few days. After routine, the meeting was addressed at some
h and in a very interesting manner, by Dr. M. A. Veeder, of Lyons, N. Y.,
had spent the day in town in consulting with Mr. Carpmael, Director of the
nto Magnetic Observatory, whose records extend over a period of half a cen-
Dr. Veeder dwelt upon the expedition to northern-most Greenland, of Lieu-
nt Peary, U. S. N., who has consented to record observations of auroræ upon
n that will enable comparisons to be made in detail with records from other
ities. The doctor expressed himself as confident that these observations
h will extend over two years, will go far to remove certain difficulties which
meet the investigator of auroræ. Dr. Veeder then took up the general sub-
of auroræ and, in reply to questions and otherwise, spoke of his hopes and
s. Members of the Society scattered throughout Ontario are assisting in
ng regular observations. Mr. G. G. Pursey read an interesting paper on
r Heat.

PUBLISHER'S NOTICES.

The subscription price to ASTRONOMY AND ASTRO-PHYSICS in the United and Canada is $4.00 per year in advance. For foreign countries it is £1 or marks per year, in advance. Recent increase in price to foreign subscribers to increase of postage because of enlarged size during the year 1892. M Wesley & Son, 28 Essex Street, Strand, London, are authorized to receiv scriptions. Payment should be made in postal notes or orders or bank Personal checks for subscribers in the United States may be used.

Currency should *always* be sent by registered letter.

Foreign post-office orders should *always* be drawn on the post-office in field, Minnesota, U. S. A.

All communications pertaining to Astro-Physics or kindred branc physics should be sent to George E. Hale, Kenwood Observatory, of the U sity of Chicago, Chicago, Ill.

For information of correspondents, the names and addresses of the ass editors of ASTRO-PHYSICS are given as follows:—

James E. Keeler, Observatory, Allegheny, Pa.; Henry Crew, Northw University, Evanston, Ill.; Jos. S. Ames, Johns Hopkins University, Baltimor

All matter or correspondence relating to General Astronomy, remitt subscriptions and advertising should be sent to Wm. W. Payne, Publishe Proprietor of ASTRONOMY AND ASTRO-PHYSICS, Goodsell Observatory of Ca College, Northfield, Minn.; and the Associate Editors for General Astronom S. W. Burnham, Government Building, Chicago Ill.; E. E. Barnard, Lic servatory, Mt. Hamilton, Cal., and H. C. Wilson, Goodsell Observatory, N field, Minn.

Manuscript for publication should be written on one side of the pape and *special care should be taken to write proper names and all foreign* *plainly*. All drawings for publication should be *smoothly* and *carefully* ma *India Ink* with lettering well done, because such figures are copied exactly b process of engraving now used. If drawings are made about double the s tended for the printed page, better effect will be secured in engraving than copy is less in size. It is requested that manuscript in French or German be written. If requested by the authors when articles are sent for public *twenty-five* reprint copies, in covers, will be furnished free of charge. A g number of reprints of articles can be had if desired, at reasonable rates.

Rates for advertising and rates to news agents can be had on applicati the publisher of this magazine.

CONTENTS FOR MAY.

PLATE XXIX.

COMET b, 1893.

Photographed by Dr. H. C. Wilson, July 11, 1893. Exposure 45 minutes.

stronomy and Astro-Physics.

. XII, No. 7. AUGUST, 1893. WHOLE No. 117.

General Astronomy.

OBABLE ADVANTAGES IN ASTRONOMICAL PHOTOGRAPHY OF SHORT FOCUS LENSES.*

REV. GEORGE M. SEARLE.

ccording to a formula well known in ordinary terrestrial pho-
rapiy, the intensity of the light received on the plate from
illuminated object, (or, if the illumination of the object be
form in all its parts, the quantity of light received per square
h) is proportional to the square of the quotient resulting from
division of the diameter of the stop, or of the lens, if a simple
nbination be used without a stop, by the focal length. This
mula plainly follows from the considerations that the total
t received by the lens from a given angular area (say of sky),
roportional to the area of the lens, and that this light is dis-
outed on a surface proportional to the square of the focal
gth.

t follows from this, that if the plates and development are the
ne, the same intensity (say of sky) will be obtained in photo-
phs taken with the same exposure, and with lenses having the
ne proportion to their focal lengths, whatever the absolute
nensions of the lenses may be.

ithin certain limits also we may assume that the intensity de-
oped on the plate will be under the same circumstances pro-
tional to the exposure, though it is well known that a limit
easily be reached, sooner of course for a brighter object than
a fainter, at which further exposure ceases to be useful, and
omes indeed injurious; and also that some time before this
it, the exposure is less of a factor than before.

lso we may assume, in the same way with due limits, that
intensity developed on a plate with the same exposure is
portional to the square of the quotient which has been given;
hence in general, that the intensity or strength of the photo-
ph will be as the exposure multiplied by the square of this

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[*] Communicated by the author.

quotient; and hence that if we desire, as is the case in terre photography, to produce for instance in the sky an inte which is the best for the balance of the picture, the exp should be proportional to the inverse square of the quotient.

If then we photograph the sky with two telescopes, one ha for instance, a twelve inch lens with a fifteen foot focus, the a six inch lens with a three foot focus, the exposure to ol the same density with the same plate and the same develop needs to be only $\frac{36}{225}$ in the latter case of what is required i former. And the sky will have to be $\frac{225}{36}$ as bright for the tv inch as for the six, to be photographed in the same time. Tl commonplace, everyday photography.

So far we can be reasonably sure of our results. But how they be applied to stellar photography?

According to abstract theoretical considerations, the inte of the light of the stars, if there be no absorption of ligh space, is proportional to the intrinsic brilliancy of their surf and is the same, no matter to what distance they are remo Remove the Sun to a million times its present distance and it look one trillionth part as bright as now; but its disc will b duced in the same proportion.

If then the intensity of the light is the same, it would seem all stars of the same intrinsic brilliancy should be photogra in the same time with the same telescope; and also that in same time they would be photographed by all telescopes ha the same proportions of diameter and focal length. Morec that time would be accessively short, as the time required photographing the Sun itself is.

These conclusions, however, are evidently false, being cont to experience. Why are they false? What theoretical reason be given?

One is quite obvious. It is that the images or, as they called, spurious discs, of stars in a telescope are not proporti to the apparent magnitudes of the stars themselves. On condition which is verified in terrestrial photography, our clusions of course depend. Take twice as much sky, giving t as much light, and in the same camera, it covers twice as r plate. But owing to various causes the cone of rays does come exactly to a point, even if emanating from a point. I suppose a star to subtend an angle of $0''.01$, as the Sun wou removed to about 200,000 times its present distance, its ir ought to cover a disc on the plate of a diameter of a $\frac{1}{20000000}$ part of the focal length; if the latter be twenty fee

xample, the image should be about $\frac{1}{100000}$ part of an inch broad.
low according to Dawes, the spurious disc of a star in a tele-
cope of twenty feet focus, which we may perhaps assume would
ave a fifteen inch object-glass, would be 0″.3, or about $\frac{1}{700000}$
art of the focal length in diameter; that is $\frac{1}{35000}$ part of a foot
r $\frac{1}{3000}$ of an inch. The effect on it, therefore, of the actual di-
iensions or of the nearness of the star is quite inappreciable.
lence at least as long as we use thc same telescope, the common
ormula of photographs has no application to the stars. The
nages of all stars being practically of the same size in the same
elescope, the intensity of their illuminations is simply propor-
ional to the whole light received, or to the apparent quantity of
ght given by the star; and the exposures will be approximately
the inverse ratio of that light; and the spurious disc being so
uch larger than the theoretical image of ordinary photography
hey all require quite a rather long exposure. The Sun, or any
ther illuminated surface of perceptible dimensions, photographs
uickly, because the spurious discs formed by each point of its
irface, overlap and strengthen each other; but the star has no
ich advantage.

The figures given by Mr. Dawes of course refer to the optical
nage; but may be taken approximately for the photographic
nage also.

Now, what will be our conclusion with regard to different tele-
copes? According to Mr. Dawes, the angular diameter of the
purious disc of a star is inversely as that of the object glass; and
ierefore, if we keep to one proportion between object glass and
cal length, inversely as the focal length; hence it would follow,
nce the real or linear diameter of the spurious disc is equal to its
ngular diameter multiplied by the focal length, that this real or
near diameter of the disc, in telescopes constructed on the usual
roportions, is the same, say $\frac{1}{3000}$ of an inch in all cases. Accord-
ig to this, then, any telescope will illuminate this constant disc
r any particular star with a light just in proportion to the area
f its object glass; and the time of exposure for any particular
tar will be, approximately, inversely as the area of the object
lass.

This seems to be the rule usually assumed; and taken with the
ther previously obtained as to stars of different magnitude,
ould form a regular guide to exposure on stars in astronomical
hotography. It is simply that the exposure should be for vari-
us stars inversely as the product of their actinic brightness mul-
iplied by the area of the object glass used.

But the question arises whether the diameter of the spurious disc is independent of the ratio of the diameter of the lens to its focal length. If we shorten the focus, keeping the diameter of the lens the same, the disc must, it would seem, be altered; of what nature would the alteration be? Even if the disc is made, on the whole, somewhat larger, as one might naturally expect, still if the light were more concentrated toward its central portion, this ought to be photographically, and perhaps also optically, an advantage. With regard to the latter point, at any rate, experience seems to show that stars are more clearly and sharply visible with short-focus telescopes than with long-focused ones of the same size of objective. The long-focus one magnifies more, of course with the same eye-piece, and ought to stand a higher power; but it is better to see a star sharply, if we want to measure its distance from another, than to have that distance on a larger scale, but not to see the star at all.

It may not be certain that short focus telescopes have this optical advantage, but it is at least possible; and with regard to the photographic image, actual photographic experiments must settle the question better than observation can do for the optical image; for not only can the determination be made more quantitatively, but prejudice is also more removed by them. If experiments show that a satisfactory image is produced on any star in a shorter time with a short focus telescope than with a long focus one of the same diameter, or that with the same exposure a fainter star can be taken by it, its practical superiority, for ordinary purposes, is proved; and probably even for micrometric measurements the disadvantage of smaller dimensions would be more than made up for by the saving of time.

I have heard of a case in which it was stated that a ninth magnitude star was photographed with a telescope of six inches aperture and three feet focus in the same time that was required for a seventh magnitude with a telescope of twelve inches aperture and fifteen feet focus. Now a seventh magnitude star is about 6¼ times as bright as a ninth; and if we take the square of the quotient mentioned in the begining we find that it is for the six inch, $\frac{1}{36}$, and for the twelve inch, $\frac{1}{225}$. According to the ordinary photographic formula then, the exposure with the six-inch should be the same as that with the twelve-inch on an object $\frac{225}{36}$ or 6¼ times as bright. In this case therefore it would seem that the ordinary formula of every day photography would work; still it would probably be too much to assume it as a general law in stellar photography.

But there really seems to be no reason why it should not be e proper formula not only for the Sun, Moon, and larger plan-, but also for most nebulas and comets. A nebula a minute of e in diameter is too large for the consideration of the matter of urious discs; and there is apparently no reason why it should t photograph according to the same laws as a piece of sky; if in this class of work, the superiority of the short focus lens in e matter of exposure would be unquestionable. Its short focus ould, of course, make the picture of the nebula smaller; but it n be enlarged, in a few minutes, as much as we please, with a oying camera.

A GRAPHICAL METHOD OF DERIVING THE APPARENT ORBIT OF A DOUBLE STAR FROM THE ELEMENTS.*

T. J. J. SEE.

or a long time it has been customary to test the accuracy of uble star orbits by comparing the computed with the observed ces, and to estimate the value of an orbit mainly by the resids of position angle. Mr. Burnham's great practical experience h the micrometer has shown that distances (especially in case close pairs) are quite as trustworthy as angles, and the thod of finding an orbit solely by means of position angles has en been discredited by absurd results of computers who discard measures of distance. That distances should be given more ight in the determination of orbits than has been customary herto is sufficiently established by Mr. Burnham's work on merous stars, and by the researches of Otto Struve on the or- of 42 Comæ Berenices (*Monthly Notices,*) vol. XXXV, p.)), which depends almost solely upon distances.

Ir. Burnham has therefore come to the conclusion that the y safe basis for the determination of a double star orbit cons in the use of both angles and distances as given directly by observers without any correction by means of graphical ves or otherwise.

Iy own recent experience in the determination of double star its confirms the validity of this conclusion. For although we ow that the graphical curve of observations will flow oothly, we never know, and, in the nature of things, never can ow what the *curvature* should be at the different points,

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Communicated by the author.

whereas if the observations are platted directly we know at least that the apparent orbit must be an ellipse, which we can easily draw by trial so as to conform to the best observations.

The graphical curve has also the additional disadvantage that it "fixes" the data, and does not enable one to go behind the orbit thus deduced, whereas if the observations are platted directly the trial ellipse may be varied at will; indeed this trial ellipse is the only interpolating curve which is at all satisfactory and it meets the conditions of the problem admirably.

In investigating the orbits of a number of stars, Mr. Burnham has found it desirable to have a short practical method of laying down the apparent orbit from the elements, so that a working astronomer might readily compare the observed places directly with the orbit without going through a long calculation. This desirable result may be obtained by means of the following simple process:

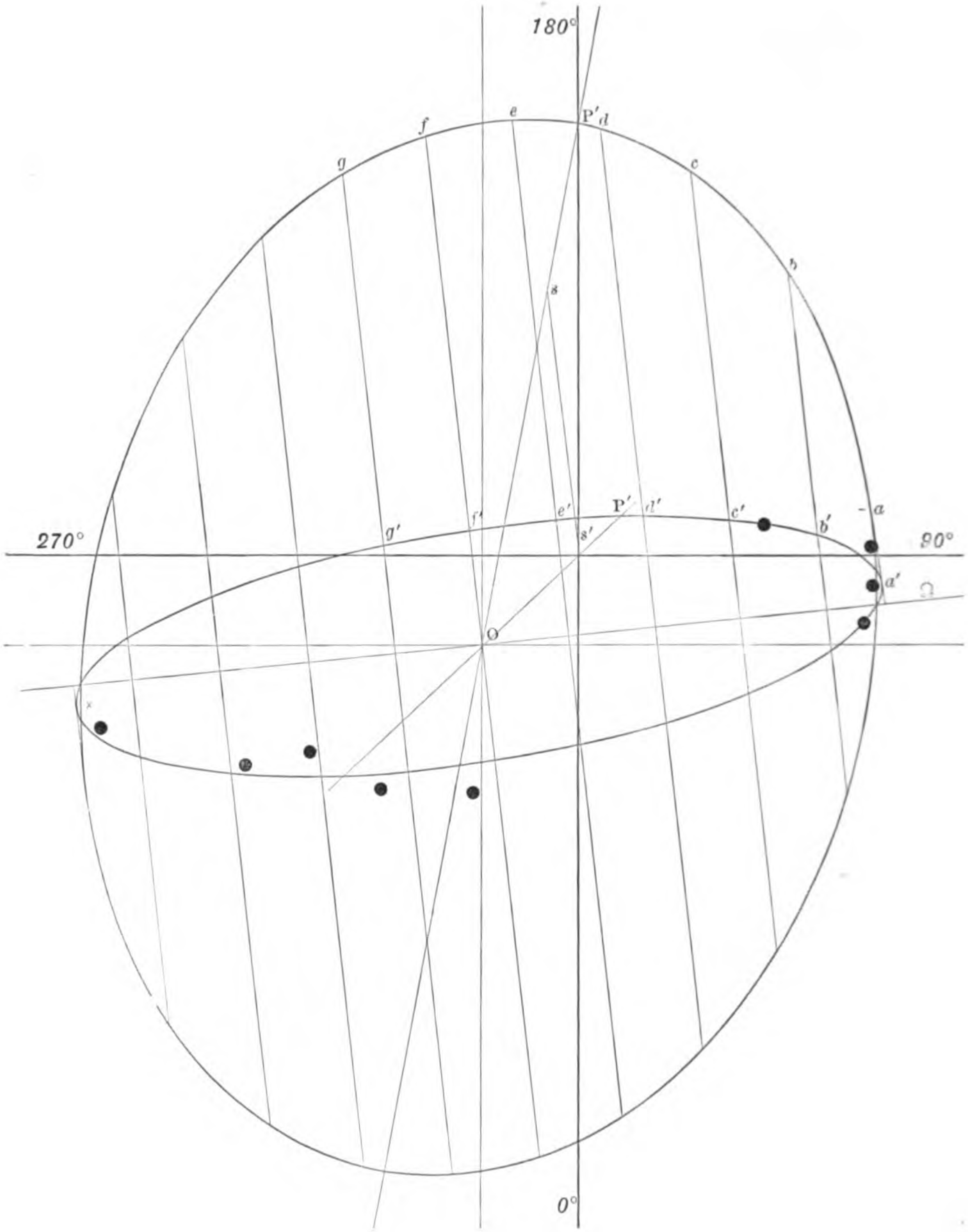
Owing to projection all diameters of the real ellipse will be shortened, except the diameter which coincides with the line of nodes (the line of intersection of the plane of the orbit with the tangent plane of the heavens). From this it follows that if from points on the arc of the real ellipse we let fall perpendiculars to the line of nodes, and shorten these perpendiculars in the ratio of cosine of the inclination to unity, we shall obtain points through which the apparent ellipse must pass; and when 10 or 12 such points have been determined it is an easy matter to draw the apparent ellipse either by means of an ellipsograph or by the free hand. To illustrate this method graphically, I shall apply it to the orbit of 9 Argûs = β 101, as given in the ASTRONOMY AND ASTRO-PHYSICS for June.

The elements of the orbit of this pair which are required for this purpose are the following:

Eccentricity, $e = 0.68$
Semi-Major axis, $a = 0''.612$
Node, $\Omega = 95^\circ.75$
Inclination, $i = 76\ .87$
Node to Periastron, $\lambda = 73\ .92$

On suitable drawing paper we lay down two lines at right angles to each other, which represent the four quadrants of position angles. The intersection of these lines will be the centre of the real orbit and also the centre of the apparent orbit. The line of nodes is then drawn through the centre, having a position angle of 95°.75. In like manner we lay down the line whose po-

PLATE XXX.



ion angle is 73°.92 + 95°.75 = λ + ☊ = 169°.67, and this will the major axis of the real ellipse.

We now adopt a convenient scale of distances, which will give distance on the drawing paper of 10 or 12 inches for the major is.

With close pairs, 0″.1 may represent one or two inches of the ale, so that the work can be done with the highest degree of acracy. From the centre the length of the semi-major axis ″.612) is laid down on the line just drawn, and the distance of e foci of the ellipse from the centre will then be *ae* (0″.612 × 58). The ellipse is then drawn in the usual manner.

We now lay off points on the line of nodes at equal distances m the centre of the ellipse, and through these points draw lines ′, *bb*′, *cc*′, *dd*′, etc., perpendicular to the line of nodes. The gths of these lines on either side are found in seconds of arc by e scale used, and these values multiplied by the cosine of the innation (cos. 76°.87 = 0.227); the resulting values are marked the corresponding lines at *a*′, *b*′, *c*′, *d*′, *e*′, *f*′, etc., on both sides the line of nodes. These points will lie on the arc of the real ipse as seen from the Earth, and when we pass an ellipse rough these points, we have the apparent orbit of the double ar.

To find the position of the star in the apparent ellipse, the disnce of the focus *s* of the real ellipse from the line of nodes is mullied by the cosine of the inclination as before, and the point *s*′ d down, which will be the position of the central star as seen m the Earth. A line O*s*′P′ drawn from the centre through this int to intersect the arc of the apparent ellipse gives the position gle of the real major axis, and the position of the real periason.

Having thus obtained the position of the central star in the aprent orbit, it only remains to draw *through the principal star* es parallel to those intersecting at the centre and marking the ır quadrants, which may now be erased. In the figure the es through the central star which mark the four quadrants are licated by heavy lines, so that they are easily recognized.

This very simple process of projection thus enables us to lay wn for inspection by the eye the apparent orbit of any star ıen the elements are properly given; and from the observed poions (indicated in the figure by black dots) we see that the aprent orbit represents the observations satisfactorily. It only nains to add that in case of retrograde motion, the angle λ hich should always be counted in the direction of the motion, while the ascending node should be taken between 0° and 180°) must for purposes of graphical representation be taken as negative, and the position angle of the major axis of the real ellipse becomes ☊ $-\lambda$, whereas for direct motion the angle is ☊ $+\lambda$, as in case of 9 Argus.

The usage of astronomers as respects the angle λ is by no means uniform, some counting it in the direction of the motion, others in the direction of increasing position angles. Now since it is very difficult to depict an orbit graphically without knowing how λ is counted, it is of the utmost importance that the method of reckoning should be uniform. Therefore I venture to suggest the following means of disentangling the confusion hitherto existing in the elements of double star orbits:

Since in case of double stars we can not distinguish between ascending and descending node, and one node must necessarily fall between 0° and 180°, that node should be taken as the ascending node; then the angle λ and the argument of the latitude u should be counted *in the direction of the motion* from this node. This will remove all obscurity in laying down the apparent orbit, and will also render the deduction of the true anomalies very simple: $v = u - \lambda$ both for direct and retrograde motion. It is here assumed, in accordance with prevailing usage, that the inclination i, never surpasses 90°. In connection with the usual elements, it would be desirable to have also the position angle of the real major axis, and the lengths of the major and minor axes of the apparent orbit. In case of 9 Argus the elements would be:

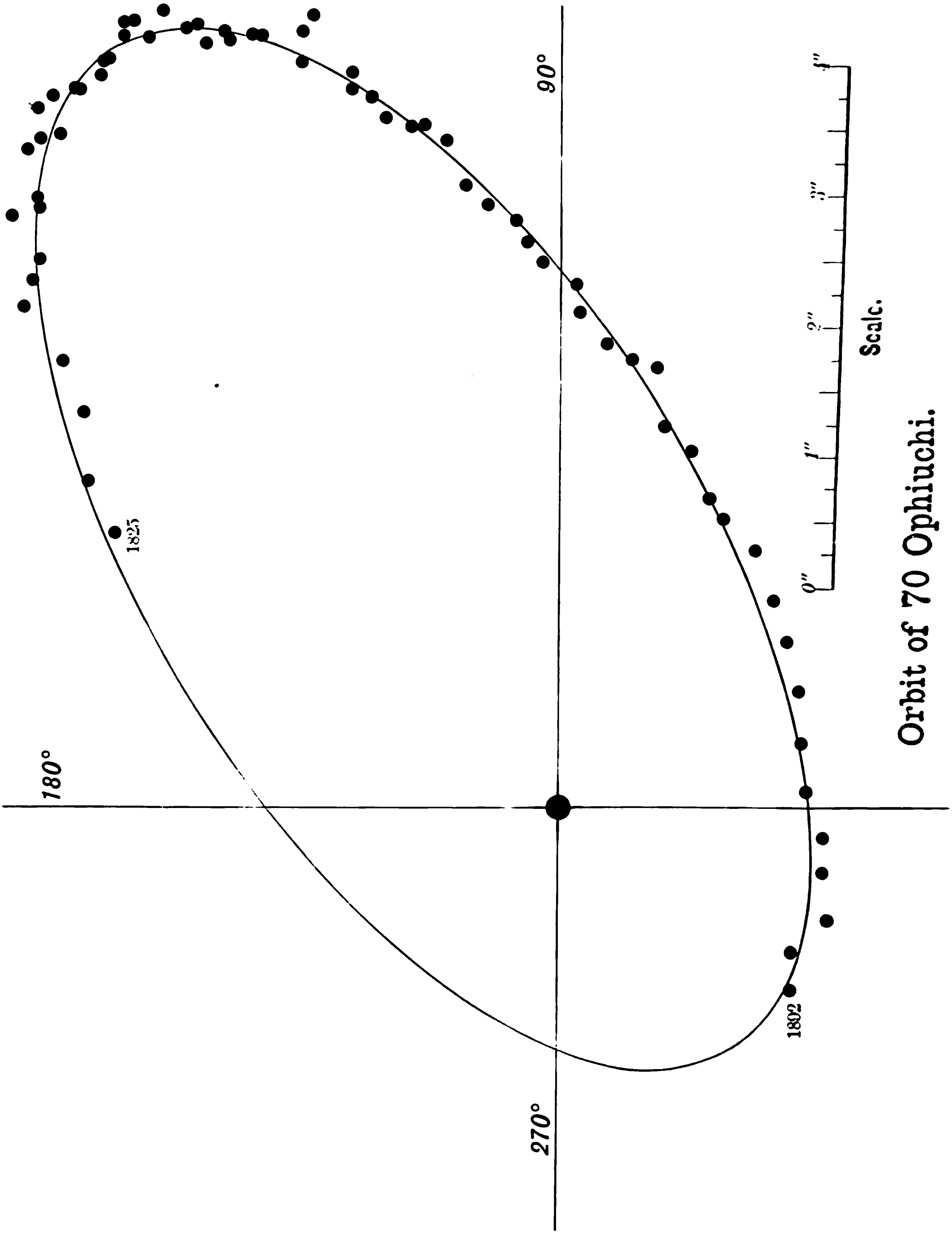
$P = 23.377$ years.
$T = 1892.706$
$e = 0.68$
$a = 0''.612$
$i = 76^\circ.87$
☊ $= 95\ .75$
$\lambda = 73\ .92$
$n = +15.3998.$

Apparent Orbit:

Length of major axis = 0″.938
Length of minor axis = 0 .276
Angle of major axis = 98°.7
Angle of Periastron = 134 .0
Distance of star from centre = 0″.15

If λ and ☊ are correctly given, these supplementary elements

PLATE XXXI.



Orbit of 70 Ophiuchi.

be derived by simply projecting the orbit as explained in this er. The agreement of observed distances with the orbit thus ived will be at once evident, while the observed angles may be estigatd by means of the law of areas.

HE UNIVERSITY OF CHICAGO.
1893, June 30.

THE ORBIT OF 70 OPHIUCHI.*

S. W. BURNHAM.

aving made a complete list of the measures of 70 Ophiuchi, I e taken occasion to get the elements of the orbit by the phical method. How well the apparent ellipse represents the ervations will be seen from the accompanying diagram. The itions given are for each year in which complete measures e been made. When measured by more than one observer, a ple mean is taken. The last measures shown are my observa-ns at Mt. Hamilton in 1892.

he following elements are derived from this ellipse :

$P = 87.75$ years.
$T = 1895.6$
$e = 0.50$
$a = 4''.56$
$i = 58^{\circ}.3$
$\Omega = 123^{\circ}.5$
$\lambda = 190^{\circ}.8$

APPARENT ORBIT:

Length of major axis	= 8″.97
Length of minor axis	= 4 .21
Angle of major axis	= 121°.6
Angle of periastron	= 117°.5
Distance of star from center	= 2″.23

he element λ is reckoned in the direction of the motion in ac-dance with the plan adopted by Dr. See to secure uniformity his respect. This quantity would be 169°.2 if measured in the osite direction, as has been done in some of the published or-.

his is one of the few binaries where the period is fairly well

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* Communicated by the author.

known. The final result will probably not differ more than one year from that given here. This orbit is substantially identical with that found by Gore in 1888. Sixteen orbits of this system have been published, with periods varying from 73 to 98 years.

CHICAGO, July 6.

THE ORBIT OF OΣ 285.*

S. W. BURNHAM.

In the SIDEREAL MESSENGER for June, 1891, I gave the apparent orbit of OΣ 285 with a list of the measures down to that time upon which it was based. From this I deduced the period but by a clerical error it is printed in the paper referred to as 72.7 years instead of 62.7. The other elements of the real orbit were not given.

Mr. Gore has recently published a new orbit of this pair in *Monthly Notices* R. A. S., for April, 1893, which differs in every material respect from the previous orbit. It is a good example of totally dissimilar results being derived from precisely the same data. It seems to me that the measures are better represented by the first ellipse; but, however that may be, it will be of some interest now, and more hereafter, to show on the same diagram the two orbits. I have carefully gone over my original diagram, and as I see no reason for changing it in any respect, it is reproduced exactly as it was given with the addition of the position derived from my measures at Mt. Hamilton in 1892. This orbit is marked A. The ellipse B is that found by Gore, using the same observations, including the last set of measures in 1892.

For a further comparison of the two, I have obtained from my orbit all the elements:

BURNHAM.	GORE.
$P = 62.1$ years	118.57 years.
$e = 0.429$	0.58
$a = 0''.387$	$0''.46$
$T = 1885.3$	1881.93
$\iota = 44^\circ.3$	$45^\circ.7$
$\Omega = 54\ .3$	$106\ .58'$
$\lambda = 180\ .0$	$161\ .4$

If the second orbit is correct, this will soon be an easy pair to measure, and it is probable that the present year will show

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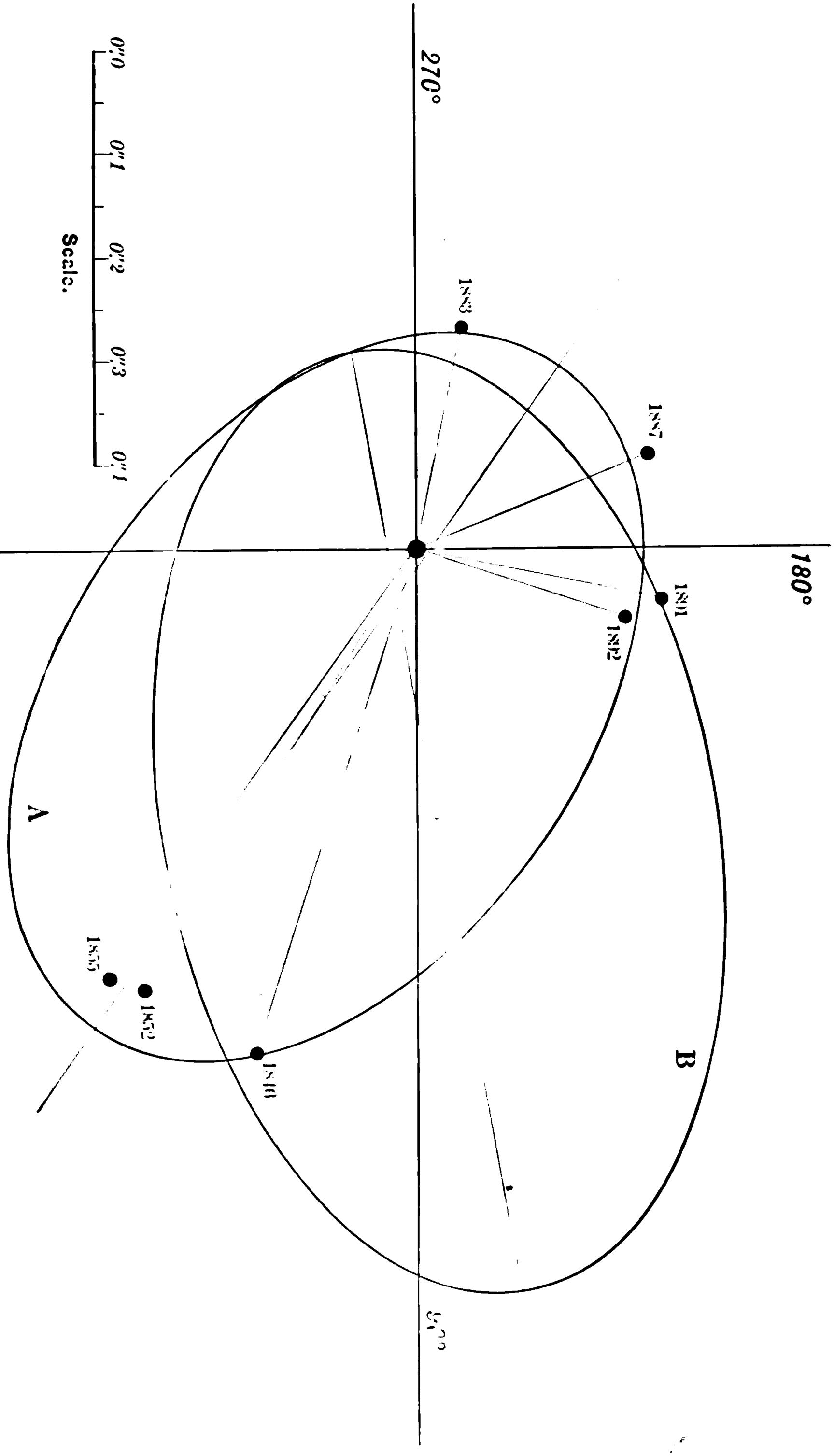
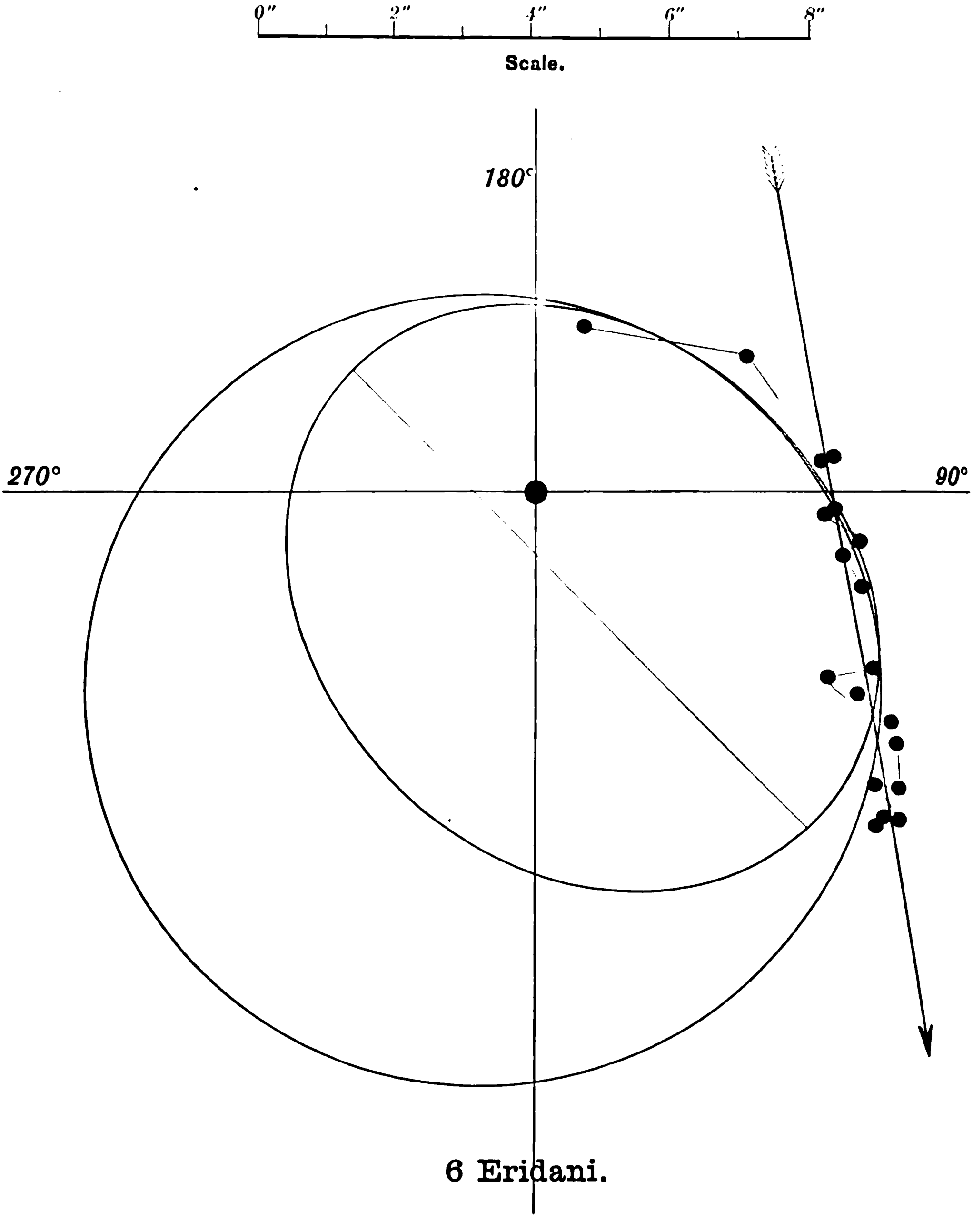
* Communicated by the author.


270°
180°
90°
0".0
0".1
0".2
0".3
0".4
Scale.
1883
1887
1891
1892
1855
1852
1846
A
B

OΣ 285

PLATE XXXIII.



6 Eridani.

hether or not the distance is really increasing. According to y ellipse the distance between the components will not exceed ″.25 for some years to come. Of course in any event the ele-ents at this time are only provisional, but annual observations r the next three or four years should define the general form of ıe apparent orbit.

I have not given a comparison of the errors of the observations ccording to the respective orbits, as that sufficiently appears om an inspection of the diagram.

CHICAGO, June 1.

NOTE. Since the foregoing was written, I have had an oppor-ınity, in company with Professor Hough, of examining this pair ı June 16, with the 18½-inch refractor of the Dearborn Observa-ory. It appeared certain from inspection that no sensible ıange in the distance had taken place since my measures at Mt. amilton in 1891 and 1892. It is a rather difficult pair with the earborn telescope, but I made on this occasion what seemed to : a fairly good measure; and obtained 156°.0 for the position ıgle, and 0″.24 for the distance. This would seem to indicate ıat the distance is not increasing, and that the shorter period is ore likely to be correct.

THE MOTION OF 6 ERIDANI.*

S. W. BURNHAM.

This is a very wide pair, but with considerable relative motion. s the declination is nearly 57° south, it is beyond the reach of l observers in the northern hemisphere. The character of the ıotion has been the subject of considerable discussion. If the ırly measures of Dunlop and Herschel are to be relied upon, ıere can be no doubt of the two stars forming a binary system, ıt all of the later measures tend to show that the motion of the ompanion is rectilinear. Four computers, upon the assumption ıat the motion is orbital, have deduced from the measures the rbit of the system, obtaining the following periods: Doberck, 17 years; Jacob, 123 years; Downing, 224 years; and Gore, 02 years.

In the accompanying diagram I have laid down the orbit by owning (*Monthly Notices*, March, 1883) and the measures as e has given them upon which the orbit is based. He did not use

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* Communicated by the author.

the last five positions, being the measures of Pollock and Sellors, but I have inserted them as having a bearing upon the question, still undetermined, of the real character of the motion. At the time of making this diagram I had overlooked the later orbit by Gore (*Monthly Notices*, November, 1887), but in this connection it is not important, since it is apparent from an inspection of the measures down to this time, that even if the two earlier positions of Dunlop and Herschel are substantially correct, the problem of the real orbit is an indeterminate one, and an ellipse which would require a period of many hundred years, even a thousand or more, will satisfy the measures as well as any period which has been found. I have drawn a circle on the diagram, which, it will be seen, represents the observations at least as well as the ellipse. It is evident that a great number of ellipses could be readily drawn which would do the same thing; therefore, even if it be conceded that this is a physical system, it will be another hundred years at least before even an approximate orbit can be found.

With respect to the nature of the relative movement, there is very little to say beyond what appears from the actual measures. It seems improbable that Dunlop's observation can be so far wrong as to be very much inferior to an ordinary eye estimate; on the other hand all of the measures since 1845 can be well represented by rectilinear motion, and Herschel's position in 1835 will be in substantial harmony if we may assume that his distance is about 1″ too small. In fact one of his estimates with the large reflector made the distance 4½″ at this time. If the change in the companion is due to proper motion, then it must have a relative annual movement of about 0″.11 in the direction of 10°. I think the probabilities are in favor of rectilinear motion, taking everything into account, but at present it is a matter of judgment only, about which astronomers may differ widely. Annual measures for the next ten years should determine this question.

CHICAGO, June 17.

A MICROMETER FOR MEASURING THE PLATES OF THE ASTRO-PHOTOGRAPHIC CHART.*

W. H. M. CHRISTIE, ASTRONOMER ROYAL.

For the measurement of the catalogue plates of the Astrophotographic Chart, the micrometric slide originally made by

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* *Monthly Notices* of R. A. S., March, 1893.

Messrs. Troughton & Simms for the measurement of the distance of *Venus* from the Sun's centre on the transit of *Venus* photographs, 1874, by the help of an auxiliary millimetre scale on plate-glass, has been adapted to the ready determination of rectangular coordinates and diameters of disks of stars on 16cm × 16cm plates.

MICROMETER FOR STELLAR PHOTOGRAPHS, ROYAL OBSERVATORY, GREENWICH.

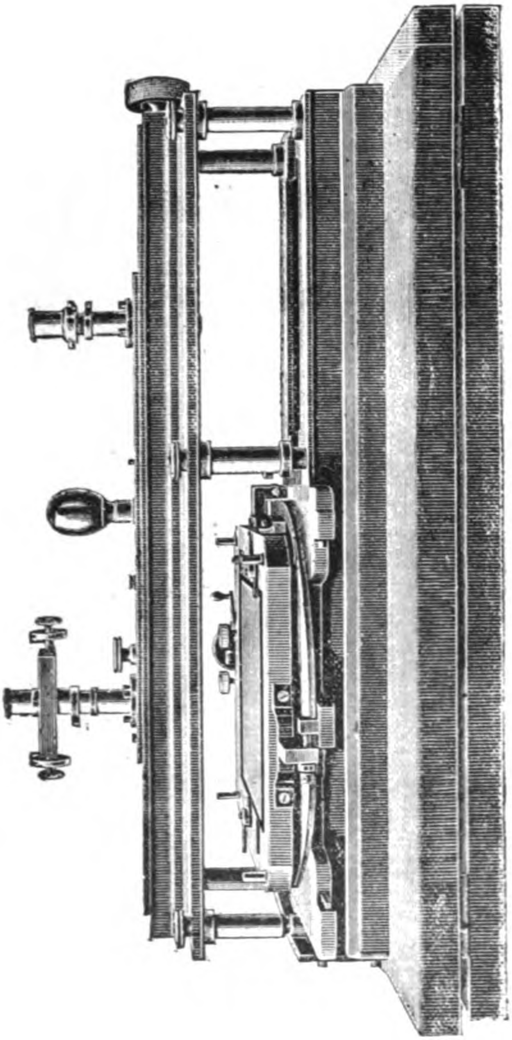
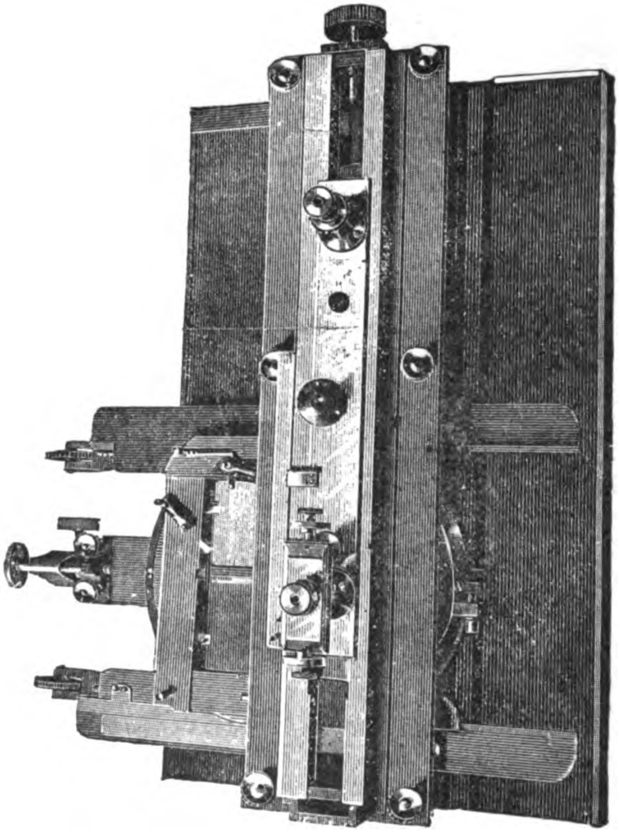


FIG. 1.—View nearly in plane of photograph.

The two figures will give an idea of the general arrangement.

Two microscopes, rigidly connected, are mounted in a longitudinal hollow frame or slide, which can be moved quickly by hand to any position in a long slide, and clamped securely. A slow motion can be given to this latter and to the frame carrying the two microscopes by means of a screw, shown on the right. The photographic plate (in a suitable frame) is viewed by the left-hand microscope (which is provided with a parallel-wire micrometer, to be described presently), and a glass scale, divided into millimetres, is viewed by the other. The plate is held in its frame, with film uppermost, in precisely the same manner as in the plateholder at the breach end of the photo-telescope, being



MICROMETER FOR STELLAR PHOTOGRAPHS, ROYAL OBSERVATORY, GREENWICH.

FIG. 2.—View from above.

pressed laterally by springs against two studs on one side (for orientation), and against one stud in the middle of the adjacent side (for fixity of position), the film side being kept in bearing with three studs in the focal plane of the microscope (at two corners and the middle of the side opposite) by three springs immediately below. The frame in which the plate is held is capable of rotation through 90°, banking against adjustable

crews so that the cross lines of the réseau can be successively
laced parallel to the micrometer slide and coordinates meas-
red in the two directions at right angles. It is, further, mount-
d in a slide perpendicular to the micrometer slide (with ad-
astment for accurate perpendicularity), so that by the longi-
adinal motion of the microscope and the transverse motion of
he photograph, any point of the latter can be brought under the
icroscope, the approximate coordinates being read off by milli-
ieter scales attached to the two slides. The whole instrument
mounted on a hinged wooden frame so that the plane of the
hotograph can be tilted to any convenient angle for vision by
ransmitted light from a reflector or white paper below, the plate
nd frame being counterpoised by two weights running over
ulleys at the top of the transverse slide.

The star to be measured having been brought near the center
f the field of the left-hand microscope by the quick motion,
he microscope frame is clamped, and, by means of the slow mo-
ion, the corresponding division of the millimetre scale is bisected
y the fixed parallel wires of the right-hand microscope. The
tar is then measured with the left-hand micrometer-microscope.
'his is arranged to give readily the reading for the center of the
tar's disc and its diameter, the principle being that devised by
ir G. B. Airy for the Reflex Zenith Tube at Greenwich. There are
wo micrometers, A carrying its own wire and also the bearing
f B, which carries a parallel wire. The screws for A and B have
he same pitch, representing $20''$ or ⅓$^{\text{mm}}$ on the plate, and the
eads are divided (in opposite directions) into 100 parts, so that
the sum of two readings 1 div. = $0''.1$. (It is intended that the
wo readings should be taken as a rule.). It will be seen that if a
nd b are the readings of two micrometers when their wires
crossed relatively to their respective heads) are placed on the
wo edges of the star's disc, its diameter would be b (the zero of
nicrometer B being adjusted for coincidence of its wire with that
f A), and the reading for its center would be $a + \frac{1}{2} b$. One co-
rdinate having thus been measured, the plate is rotated through
0°, and the other is similarly obtained, while the photographic
nagnitude is inferred from the measures of diameters (by micro-
cope B).

By this arrangement it will be seen that the positions of stars
an be expeditiously found without the necessity for measurement
f the lines of the réseau, and thus great labor may be saved.

REV. CHARLES PRITCHARD, D. D., F. R. S.*

WILLIAM E. PLUMMER.

I regret to have to inform you of the death of the Rev. Charles Pritchard, Savilian Professor of Astronomy and Director of the Oxford University Observatory. The deceased Professor was in the 85th year of his age, and to within the last few days was able to take an active part in the conduct of the Observatory and in the duties connected with his chair.

It was not till Professor Pritchard was considerably advanced in life, that he began to take an active share in astronomical research or to give signs of that energy and zeal which characterized his later years. In 1866 he was made President of the Astronomical Society, and this seems to have been the turning point of his career, for shortly after, he was appointed Savilian Professor of Astronomy, in succession to Professor Donkin, and then began that energetic conduct of the University Observatory with which your readers are familiar. It may be as well to recall that at that date (1870) the University of Oxford possessed no Observatory and no instrumental equipment. It may not be unnecessary to remind your readers that the control of the Radcliffe Observatory and its connection with the Savilian chair of Astronomy had ceased many years previously, and from the time of the appointment of Mr. Johnson to the duties of the Radcliffe Observer, the University had remained without any adequate means of educating its students in astronomy or of conducting any series of observations. This defect Professor Pritchard set himself immediately to rectify, and found the University eager to assist him. Under these happy circumstances a small but well equipped Observatory was at once commenced, and this was fortunately enlarged by the munificent and well-timed gift of the late Dr. Warren de la Rue. This latter contribution consisted chiefly of reflectors, and since the University had ordered a refractor from Sir Howard Grubb, the Professor early found himself in possession of the necessary instrumental means to prosecute his inquiries in whatever direction he pleased. He first turned his attention to the observations of double stars and comets, but abandoned these branches of observations as they did not permit any scope to originality. Meanwhile he kept steadily in view a proposal made to him by Dr. De la Rue to determine the Moon's physical libration by means of measurements made on negatives

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* From *Astronomische Nachrichten*, No. 3171.

of the Moon. The experience gained in this class of enquiry convinced Professor Pritchard of the superiority of the measurement of the photographic image over the more direct measurements made in the field of the telescope, at least, in some instances. In a climate where the observations were peculiarly liable to interruption from cloud he appreciated the possibility of effecting an observation in a few seconds whose measurement could be leisurely completed at another time. The lesson he learnt in those days with the old collodion films was destined to bear fruit later on; and his devotion to photography and his belief in its accuracy deepened as newer processes put within his reach impressions of fainter objects and more varied detail. In this spirit he was prepared to give the greatest assistance and cordial support to he scheme of the late Admiral Mouchez and the Brothers Henry. n the earliest days of that scheme, and before the slower machin- ry of departments of state could be made operative Professor Pritchard assisted again by his friend Dr. De la Rue, was urging on Sir Howard Grubb the necessity of providing him with a pho- ographic object glass, of the pattern recommended by the Paris Congress; and the writer well remembers the mortification felt y the late Professor at the delay that the difficulties of manufac- ure interposed between the inception and the completion of the cheme. Some portion of the interval was practically and use- ully filled by photometric comparisons carried out by means of a wedge of neutral tinted glass. This "wedge photometer" had een devised for the purpose of forming an Uranometria on trictly scientific lines. It had been used not only for the determi- ation of the magnitude of the stars in Argelander's Uranometria ut it had served likewise for investigating the amount of light bsorbed by the atmosphere. This inquiry was conducted both n Egypt and in Oxford, and the result is in practical unanimity with the more recent inquiries. The importance of these photometrical researches was recognized by the Royal Astronomical ociety, and their gold medal was awarded to him in conjunction with Professor Pickering, who had been engaged in stellar pho- ometry about the same time.

But Professor Pritchard returned to photography with more han his old ardor. Preliminary enquiries had convinced him of he accuracy of his measurements on photographic films and he elieved that he held in his hand the means of rapidly increasing ur knowledge of the parallax of the fixed stars, and with this iew he sought to determine the distance of the stars of the sec- nd magnitude, visible at Oxford. How he succeeded is known to the readers of the *Astronomische Nachrichten.* He derived the parallax of some thirty stars, principally of this magnitude, and believed that he thereby made a step towards the solution of a great cosmical problem. This last work received the reward of the medal of the Royal Society, but the Professor did not think for one moment of resting on his well earned rewards. Other problems were engaging his attention and his indefatigable zeal overlooked the age at which he had arrived and in the midst of his work he succumbed, on Sunday, May 28, after only a few day's illness.

THE DEVELOPMENT OF THE SOLAR SYSTEM.[*]

DANIEL KIRKWOOD.

Were all members of our planetary system originally solid?

A consideration of facts apparently bearing upon this question led the present writer a few years since to a negative conclusion. If either nebulous or gaseous, or if from any cause readily disintegrated, the dismemberment of the external parts would be a question of circumstances. Assuming the system of Mars and his satellites to have originated as in the cosmogony of Laplace the mean density of the primary when filling the orbit of Phobos was about $\frac{1}{21}$, the present mean density of Mars being unity. The tendency to the centre of Mars was 0.107. The weight of one pound on the surface of Phobos was $\frac{1}{360000}$th of one pound, the radius of the satellite being the same as the present. In other words, the tendency of a disconnected mass or particle at the surface of Phobos would be greater *toward the primary* than to its own centre. If, therefore, free to move, the process of ring formation, as in the case of Saturn's annuli, was in operation at an epoch indefinitely remote. The origin of Saturn's rings may thus be explained. A similar process may also be applied, as has been shown by Pickering,[*] to the satellites of Jupiter, especially to Barnard's.

The ancient history of the solar system—the origin of comets and of meteoric streams—the question whether cosmical rings precede or follow planetary formations—the zodiacal light, its origin and explanation, all afford questions for future discussion, and promise results of no ordinary interest.

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[*] Communicated by the author.

[†] ASTRONOMY AND ASTRO-PHYSICS, June, 1893, p. 486. See also "The Formation of Rings as a Process of Disintegration," by Dr. M. W. Meyer, ASTRONOMY AND ASTRO-PHYSICS, May, 1893, p. 410.—"Analysis seems to indicate *that planets and comets have not been formed from rings, but rings from planets and comets.*" SIDEREAL MESSENGER, April, 1885, p. 72.

ASTRONOMY IN RUSSIA.*

S. W. BURNHAM.

Ve are sorry to learn that astronomical work at the Observa-
'y at Abastuman, Tiflis, in the mountains of south-eastern
ssia, has been permanently discontinued, and Professor Glas-
ıpp has returned tothe Observatory of the Imperial University
St. Petersburg. Professor Glasenapp who is well known as
e of the leading astronomers in Russia, and one of the most en-
etic and expert observers with the micrometer to be found any-
ıere, has done a large amount of most valuable work in several
ds, and particularly in the measurment of double stars. It was
t only thoroughly done, but promptly published, and made
ailable at once to other astronomers working in the same
ds His observations show conclusively, not only from the
ount of work done, but the character of the stars measured
th a small equatorial, that the site of Tiflis was remarkably
orable for astronomical work. If one may judge by results,
l certainly there is no better way, no Observatory in Europe
s so favorable a location, and it would be difficult to name one
ewhere, aside from that at Mt. Hamilton, where the atmos-
eric conditions are equally favorable. The advantages to be
ned by placing telescopes on moderately high mountain eleva
ns have been so thoroughly demonstrated that this is no
ger a debatable question. The gain thus secured in the greater
ity, steadiness and transparency of the air, to say nothing of
increased number of clear nights, is a very important factor
the results obtained, and will be best appreciated by those
o have had an opportunity to observe under such conditions.
'or more than half a century Russia stood at the head of all
world in the discovery and measurement of double stars.
e two Struves secured immortality by their great work in this
oortant field, and the fame of the Dorpat and Pulkowa Obser-
ories rests upon the same secure foundation. Of late years
y little has been done, or published, at the last named Observa-
y, and the great 30-inch equatorial, the second largest tele-
pe in the world, seems to have been devoted to other than mi-
metrical work so far as one can tell from official and other
olications. Professor Glasenapp, with optical means vastly in-
or to anything used by his illustrious predecessors, has under-

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* Communicated by the author.

taken to place his country again pre-eminent in this field. He has already accomplished much, and with an instrument even as large as the old Pulkowa refractor, it is certain he would secure brilliant results. Unfortunately the telescope of the Imperial Observatory is a small one, but doubtless the Russian government will place him in a position to carry on with more powerful instruments the work inaugurated at Abastuman.

COMET *b* 1893.*

W. W. PAYNE.

This new comet was almost simultaneously discovered at two places, Alta, Iowa, and Salt Lake City, Utah. Telegraphic announcements also from the two places reached us almost simultaneously. The discoverer at Salt Lake City was Mr. Alfred Rordame and the time reported was July 8, at 10 o'clock P. M., supposably Mountain time. The message was sent to Dr. Lewis Swift of Rochester, thence to Harvard College Observatory and then, in cipher, to Goodsell Observatory, being received at the last place at 7 o'clock and 20 minutes Monday morning, July 10. At Alta, Iowa, July 8 at 9 o'clock 30 minutes, Central time, Charles Johnson and James Miller saw the comet with the naked eye and reported it to David E. Hadden, a well-known amateur observer of that place, who is regularly watching the northern skies for auroræ on Dr. M. A. Veeder's plan. On Sunday evening Mr. Hadden observed the comet and telegraphed to Goodsell Observatory the same night, asking what comet it was. The telegram was not received until Monday morning at 8 o'clock and 35 minutes. The messages were both behind time, and afford another common example of the kind of telegraph service the public has to endure. Mr. Hadden's letter written on the 10th was received Tuesday morning. From that letter we take the following paragraph:

"It was first observed here about 9 o'clock Saturday night, July 8, visible to the naked eye, but no telescopic observations were obtained until last evening (Sunday) when the comet had increased much in size. It has a bright large nucleus with much nebulosity surrounding, and for about 5° the tail is narrow and straight. Its full length could be traced for a distance of about 15° in a N. N. E. direction. There are indications that a faint

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* Communicated by the author.

iall companion tail extends for a short distance on one side of
e "head." Its approximate position for July 9, is, right ascen-
on 8^h 5^m, Decl. 49° north. It appears to be moving very
pidly."

As far as appears from telegrams and letters pertaining to the
scovery of the new comet so far received, the observers at Alta,
wa, saw it about one hour and a half earlier than others,
ough the claim of Mr. Rordame of Salt Lake has been usually
mitted heretofore. His certainly is an independent discovery.
nother letter received from Mr. Hadden under date of July 14,
ds a fact of some interest. He says:

'About 9:30 P. M. on the previous night, July 7, I examined the
rthern sky as usual for auroras, in coöperation with Dr. M. A.
eder's plan, and noticed this object in the constellation of the
nx, but it appeared merely as a large diffused or hazy star with
tail visible to the naked eye; hence, I did not suspect the nature
the object, and made no telescopic observation; the following
ening (Saturday) the comet with the bright short tail was eas-
picked up by Messrs. Charles Johnson and James Miller."

From these statements it seems probable that the comet was
inconspicuous object preceding the 7th of July, that it was eas-
visible to the naked eye on the 8th, on the 9th increasingly
ight in regard both to nucleus and tail, and that on the 10th
d 11th it was at its best so far as observations at the present
ne show.

On account of clouds the comet was not seen at Goodsell Obser-
tory on Monday (10th), but was observed well on Tuesday
ght. The position obtained on July 11.720 by the aid of the
.2-inch refractor was as follows: right ascension 9^h 09^m, decli-
tion + 44° 49′.

This position was taken by Dr. H. C. Wilson and Professor
avenworth of the State University who is spending a few
eeks at the Observatory for the opportunity of doing some as-
onomical work in the line of measuring difficult binary stars.
On the same evening also, at 10 o'clock P. M. Central time, Dr.
ilson obtained two photographs of the comet, by the aid of the
4-inch photographic telescope and an ordinary camera attached
the tube of the telescope. The exposures were simultaneous,
e former lasting for 35 minutes and the latter 45 minutes. The
ontispiece to this number is the camera picture enlarged about
2 diameters. It is a photogravure reproduction and fairly well
esents the detail of the original plate. The two prominent star
ails in line with the nucleus and about five degrees distant are ι

and κ Ursæ Majoris. On the same side of the tail and near the edge of the plate will be seen two other trails fully as bright and nearer together; these are θ Ursæ Majoris. A large number of other stars may be identified by the aid of a good star map. The length of the tail as shown on the original negative was fully 12°. A greater length could probably have been photographed if the field of the camera had been larger, or if the coma had been placed outside of the center, so that the field would have covered more of the tail. By the naked eye the train could be traced, at the same time, fully 18°, fading from view in the region of small stars near β Ursæ Majoris.

The structure of the tail is shown in the plate much better than it was seen in the telescope at that time. Three streamers are noticed about the head. One on each side of the train, extending several degrees backward from the head and making a small angle, with the tail are the most prominent ones. The prolongation of the nebulosity towards a near star at right angles with the tail was a feature noticed also in the telescope. On the original plate the divisions of the tail extending from the region of the coma to its extremity can be easily followed. These markings could not be seen in the telescope, and were not known here until seen on the photographic plate. Only one streamer was observed visually and that was so faint as to be uncertain to all observers. The elongation of the nebulosity at right angles to the train was also suspected visually by two observers.

A number of other good photographs of the comet were taken on subsequent evenings, a description of which is given elsewhere in this number.

The nucleus of the comet was measured by Professor Leavenworth, on the evening of the 11th and was found to be 8″ of arc in diameter, while the micrometric measure of the coma was 78″. The coma was about the brightness of a second magnitude star. There was no detail to be observed in either, worthy of mention, beyond that which has already been given.

On the morning of July 13, a telegram was received from Harvard College Observatory containing the elements and the ephemeris of the comet computed by Professor Lewis Boss of Dudley Observatory, Albany, N. Y. These elements were known to be only roughly approximate, having only one day intervals between the observations from which they were derived. It was noticed at Goodsell Observatory on the 13th and after that date that the errors of the ephemeris both in declination and right ascension were so great as to indicate considerable error, either in he places used by the computer or in finding his results from hem. In view of this a parabolic orbit with observations of two lay intervals was computed at the Goodsell Observatory by Proessor Leavenworth and Dr. Wilson and the result obtained vill be found under Comet Notes in this issue.

The fine auroral display witnessed on the evening of the 15th vith its wonderful curtained bands reaching nearly to both horiions, east and west, was in no way connected with the comet, lthough some observers seemed to think so from current newsaper reports. Its spectrum showed a single bright line, presumably the usual auroral line so called.

We have not yet been able to verify the reported discovery of a small comet within the train of Comet *b*, recently found on the hotographic plates taken at the Lick Observatory.

GOODSELL OBSERVATORY,
July 19, 1893.

THE ZODIACAL LIGHT.

Arthur Searle of Harvard College Observatory, has recently ublished in the Annals of that institution, Vol. XIX, Part II, a aper entitled, *Researches on the Zodiacal Light*. It is a discusion of the results obtained at Harvard College Observatory by revious observers and by himself on that subject. "A large art of the treatise relates to the phenomenon of Gegenschein or ounterglow, the observations of which at other places, as far as hey have come to the notice of the author, are here collected and ompared with each other, and with those made at that Obseratory." The period of time covered by the observations reorted is from 1840 to 1890. Those from 1874 that were reorded at Harvard were principally made by the author of this aper. But he is careful to say in the outset that the Zodiacal ight has never been regarded at the Harvard Observatory as a rominent subject of investigation, and that the information reating to it which is derived from the Observatory records comrises such facts as could be collected, at irregular times, during he intervals of more systematic work. Notwithstanding this mperfection and haste of the observations, it is apparent that hey exhibit facts which may be serviceable in leading to better nd more correct opinions in regard to the Zodiacal Light.

The first query raised is, whether or not the Zodiacal Light is a henomenon that is constant or variable in brightness if impediments to observation are not considered. The answer to this query is drawn from the experience of fourteen seasons of observations at the Harvard Observatory which shows that the phenomenon has been nearly, if not absolutely permanent, "and seldom subject to any large variations." These seeming variations can not be certainly established, owing to the defects of observations already referred to, as well as others that might be easily named. Observers have noticed, or spoken of, three phases of variation; 1, Variation in light from minute to minute, 2, Variation from day to day, and, 3, Variation from year to year. The author's decisive test for the first phase of apparent variation is the simultaneous observations by different observers not acquainted with each others conclusions. In the case of slight variations due to atmospheric changes, it is suggested, that, perhaps, sufficient photometric observations of stars in different parts of the sky, accompanying the observations of the Zodiacal Light, might remove this difficulty.

The variation of the Zodiacal Light from day to day, appears to be true from a few observations, but the author still thinks that these observations may possibly be misleading, and states reasons why or how they may be so, and they certainly seem reasonable in the absence of crucial tests, similar to those named for the preceding phase, as this second one is much like the first in kind, if the average brightness of the Zodiacal Light for one evening be compared with that of another.

The third phase of supposed variation from year to year, one might expect would be less conclusive, from observation than either of the preceding ones, yet the author cautiously says: "If we may venture to draw any inference from the record of observations as a whole, it may be said slightly to favor the hypothesis of a variation in the Zodiacal Light coincident with the variation of the quantity of solar spots, and ot auroral displays, but the support thus obtained for that hypothesis is certainly very feeble." The evidence, then, is undecisive in regard to the variation of the Zodiacal Light in either of these three ways.

Interesting associated facts do appear that may be named in this connection. For example, the ordinary brightness of the central parts of the Zodiacal Light has been estimated by previous observers to equal, or exceed, that of the Milky Way, at the same altitude, and these estimates are confirmed by a few of the Harvard observations in 1881 and 1883.

It is also noticed that the Zodiacal Light becomes fainter as the evening advances, but it can be traced to greater distances from the Sun. The form and position of this phenomenon has always claimed attention. Observers in different latitudes vary somewhat in regard to the position of its axis. Some have said that the apparent position varies with the inclination of the ecliptic to the horizon, moving towards the upper side of the ecliptic as the altitude of the ecliptic diminishes. This effect might possibly be due to atmospheric absorption, that could not be certainly decided without further evidence.

Another feature of interest is the brighter interior and the fainter exterior portions of the Zodiacal Light. This stronger interior light is not of uniform brightness, nor is it as bright near the vertex as it is in the brighter portions of the diffuse light at a smaller altitude. If the eye is swept across the axis from north to south, it is noticeable that, at a point considerably within the extreme boundaries of the light, there is a rapid decrease of brightness indicating a secondary boundary between an inner and an outer cone. This is a delicate observation, but it is also one of very unusual interest for some observers.

Another class of phenomena associated with the Zodiacal Light may now be noticed in order. We refer to the so-called "Gegenschein" as designated by Brorsen, which means a slight glow of light about 180° from the Sun, and also the belts or bands of light which have been observed in the sky, especially those in the Zodiac supposed to have some relation to the Zodiacal Light. Better observations of these phenomena have been made than of the ordinary Zodiacal Light. The apparent extension of this phenomenon, in the months of November and December, as far as the Pleiades, as a narrow band of light, was first examined at Harvard Observatory in 1875. This had been noticed by previous observers. But whether or not the band thus observed is a part of the Zodiacal Light seems questionable, because portions of the same band are so situated that its origin, as some think, may belong to another locality. The real nature of these Zodiacal belts, and their true relations are themes worthy of careful study.

There seems to be no doubt of the existence of the "Gegenschein" or the "Counterglow," as it is sometimes called, for observations of it have been too frequent and too general; but that these observations are sufficient to determine its nature is yet very doubtful. After the consideration of various hypotheses in regard to the origin of the Zodiacal Light, that which ascribes it to reflection from small meteoric bodies, or even meteoric dust, seems more probable than that of any other. This hypothesis is by no means regarded as strongly probable from known proofs, because the most natural suppositions that have been made for the distribution of meteoric dust in the region of the Zodiac have not been verified by the results found in the use of analytic methods, involving equations that are simple enough in themselves, but whose predictions fail to be certainly verified by observation. For example, if this meteoric matter be assumed to be distributed not evenly in the Zodiacal belt, but rather diminishing in density with increasing distance from the Sun, and more rapidly so than has hitherto been supposed, but that this decrease is checked after a time, and that a considerable quantity of this finely divided matter accompanies the visible asteroids around the Sun, we have as satisfactory a conjecture as any known; but the results of theory are not verified in the "Gegenschein" and the bands and the variations in the Zodiacal Light by observation, as fully as is desired for a satisfactory scientific result.

It would be profitable for any one to follow the discussion of this paper more closely, to notice the tabular evidence it furnishes and the details of statement presented, as well as the more geneneral conditions which herein have been too briefly stated to do it justice.

SYSTEMATIC STUDY OF AURORAE.*

W. W. PAYNE.

It is with marked interest that we have noticed the recent developments of a scheme for a thorough, comprehensive and a more systematic study of the phenomena of the Aurora. Heretofore, generally, the observations of these and other related phenomena have been made in a desultory way, as the interest of individual observers would prompt them to do, when displays were either obtrusive, or easily seen by the watchers of the nightly skies. The observing-books of astronomers, the weather records, the casual studies of physicists, and other similar sources, furnished the greater part of the data for the work of the meteorologist, in this part of his science, and, apparently he has made the most he could of this kind of raw material, in trying to determine the nature of the aurora and the laws which govern its manifestation. Much theory and speculation concerning the meaning of the aurora have been advanced by scientists, in all time past, but the real data to support the theories have been sadly wanting, so

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* Communicated by the author.

that no large generalizations could be made that would gain the assent of scholars, and consequently there has been very little gain in knowledge concerning it during the last half century.

For some time past, as the readers of this journal know, Dr. M. A. Veeder, of Lyons, N. Y., has been himself giving large attention to the study of the Aurora. He has formed a plan and put it into execution, by which a large number of observers in the United States might coöperate systematically in observing auroral displays. Not satisfied with the limited area of the United States, Dr. Veeder has more recently sought to extend his system to all available parts of the world, and it must be encouraging and gratifying to him to realize the success already gained in this wider field. Some account of this was given in a recent issue of the New York *Sun*, as follows:

"The fact that scientific men regard it as desirable to make these world-wide observations, so that simultaneous records from all parts of the world may be compared, is shown by the hearty endorsement and co-operation they are giving to Dr. Veeder's project. In the far north Mr. R. E. Peary, who is about to sail for Murchison Sound, Greenland, where he will erect his camp in 77 degrees 30 minutes north latitude, will give particular attention to recording his observations of auroral phenomena. On his way north he will also arrange for observation at Godthaab and Godthavn in South Greenland. Mr. George Comer, an officer of the bark Canton, now on a whaling voyage, will record observations in the immediate neighborhood of the magnetic pole itself, near the northern part of Hudson's Bay. It is expected that Father Tosi, a missionary priest in Alaska, will interest himself in securing observations in that region where auroras are more numerous than at any other point in the world. Other records of interest will be collected in Iceland, Scandianvia, Finland, Siberia, Tasmania and New Zealand."

It is true that during the international polar expeditions of 1882 and 1883 many observations of the aurora were recorded in high latitudes, but no special provision seems to have been made for comparison with those made simultaneously in lower latitudes. It is now proposed to remedy this defect. Many observers are being secured on the continents of America and Europe, and ocean observations are being provided for by the distribution of blanks and instructions through the hydrographic offices of the United States and the Deutsche Seewarte. Mr. Robert H. Scott, Secretary of the Meteorological Service of Great Britian and Ireland, has presented the matter of coöperation to the Kew

Committee of the Royal Society who have specially magnetic and meteorological research in charge. The United States Ministers at Stockholm and St. Petersburg have brought the matter to the attention of the proper authorities in those countries. Assurances of active sympathy and support have been received from many observatories, particularly those devoted to magnetic work and to observations of the Sun. Especially satisfactory in this regard is the correspondence which has been had with such institutions as the Naval Observatory, Washington; the Toronto Magnetic Observatory, and Harvard College Observatory on this side of the Atlantic; and Pulkowa Observatory, Russia; Meudon Observatory, France; Kiel Magnetic Observatory, Germany, and many others. Scientific associations also are furthering the proposed researches in one way or another, as, for instance, the "Astronomical and Physical Society of Toronto," the "Astronomical Society of Michigan," the "Rochester Academy of Science" of Rochester, N. Y., and others. It is a curious and suggestive fact that members of the engineering profession appear to be as much, if not more, interested than any other class. Physicists in several universities also are in touch with the progress of the research, and arrangements have been made so that it will be possible to submit questions that may arise that will be suitable for experimentation to experts equipped with the best possible laboratory facilities. There are a multitude of questions in respect of the sources and method of propagation of auroral luminosity that may come in the course of collecting observations that will afford opportunity for exceedingly interesting experiments. The relations between auroral phenomena and meteorology, which will appear more fully in the course of this article, are such that there is certain to be increasing interest on the part of all who are interested in weather matters.

The method of observation which it is proposed to employ is very simple and requires but little time. Each observer coöperating will indicate on the blanks supplied for the purpose the absence of the aurora. Whenever this fact has been verified by observation he will enter the figures denoting the exact time at which the observation was made in the proper space in the blank. On the other hand the presence of the aurora will be indicated by writing the word "aurora" and recording the descriptive matter on the part of the sheet left vacant for that purpose.

The facts which it is especially desired to learn are the exact times of sudden changes in the brightness of the aurora, the extent of sky which it covers, and its position relative to the true north. In case observations are not made the spaces are simply to be left blank. Each blank sheet prepared in this way covers an entire month, and is conveniently arranged so as to enable comparisons to be made at a glance between the records from different stations.

This scheme of observation has been in operation for years under the direction of Dr. Veeder. It is found that when the times are accurately given in the manner described, and the absence as well as the presence of aurora are noted, very interesting facts in regard to local distribution and the source of auroral luminosity are brought to light. It is possible in this way, also, to secure perfectly reliable information in regard to the various forms of periodicity which the aurora exhibits, some of which bid fair to be of the utmost importance in various ways. Of these perhaps the most interesting are the diurnal recurrences of the phenomena which exhibit a definite relation to certain hours of local time, even in the Arctic region, where observation is possible in winter without interruption throughout the entire twenty-four hours. It is also found that these auroral phenomena are particularly noticeable at intervals of twenty-seven and one-quarter days, corresponding in time to the synodic revolution of the sun, or, in other words, a revolution of the Sun on its axis as viewed from the earth, which is advancing in its orbit in the same direction in which the sun is revolving on its axis, thus lengthening somewhat the sun's apparent rotation period. Here are some of the facts and inferences already obtained by this method of research which justify its proposed continuance and enlargement.

Terrestrial magnetism has thus far been but little understood, but what is already known in regard to the local distribution of the Aurora and the periodicities which it manifests, intimately associated as they are with like peculiarities in the behavior of terrestrial magnetic phenomena in general, justify the expectation that it will shortly become possible to give a simple and complete explanation of the arrangement of the entire magnetic system of the globe and of the changes which it undergoes. Not only the well-known eleven-year cycle, but also the secular changes requiring centuries for their completion, and likewise the fitful and apparently irregular variations known as magnetic storms, promise to become explicable in a manner entirely consistent throughout.

. . . .

The interest at present manifested in connection with the proposed observations is very encouraging, and it is really gratifying to learn that there are so many who are willing to make some sacrifices for the purpose of advancing a research of this kind whose only recompense may be a feeling of satisfaction that knowledge is being increased. Those who may wish to coöperate may secure all information desired from Dr. Veeder of Lyons, N. Y., in whose hands the arrangement of details has been left. Mr. Peary's expedition will record observations whenever possible during the next two years. It is desirable, however, that the observations in lower latitudes be continued as far as possible throughout the year. In any event, the results of Mr. Peary's expedition with the associated system of auroral observation will be watched with lively interest by many who appreciate the magnitude of the interests involved."

Since the above was written we learn from Dr. Veeder that arrangements for coöperation throughout the Russian empire have been completed, and that observations have been provided for at the observatories of Archangel, Pawlosk, Ekatrainbourg, on the Ural mountains, and at Irkutsk in Siberia and at other points. Application has been made by the director of the Solar Section of the British Astronomical Society for necessary information and facilities to coöperate. Similar requests are being made by individuals and institutions in Europe and America. For example, the Rev. Francis Barmien stationed at Kozyrevski, on the Yukon river, Alaska, takes a deep interest in this movement and will devote much of his spare time to observation.

The Director General of the Italian Meteorological Service has expressed his approval of the purposes of the research and promises to aid it in every way possible.

The Danish government has given instructions that at all meteorological stations in Greenland and Iceland observations be made of the aurora borealis to be compared with those made in connection with the Peary expedition.

Professor W. H. Preece, the well-known English electrician, connected with the government telegraphic service of Great Britian, will co-operate by causing records to be made of all earth currents on English telegraph lines in a manner suitable for comparison with the records of the aurora that are being secured.

The New York hydrographic office has called for a further supply of blanks for recording observations of the aurora, those previously sent having been exhausted, having been issued to ocean steamers.

Professor Carpmael of the Canadian meteorological service has supplied the names of a large number of observers very favorably situated throughout the Dominion of Canada who will take observations of the aurora under most favorable conditions in the very midst of what is known as the auroral belt.

It seems now evident that astronomers and mathematicians will also heartily join in the study of the aurora. Solar photography could do much in giving exact data pertaining to the condition of the solar surface for comparison with terrestrial phenomena. The mathematician will find expression for the forces that produce regularly recurring effects, and the mechanician will devise the new instruments needed to furnish new data for verification in cases where existing ones are ill-adapted or insufficient to do the work.

LONGITUDE OPERATIONS AT GREENWICH AND PHOTOGRAPHIC WORK.*

Immediately after visitation day last year, operations were commenced for the re-determination of the longitude of Paris. Four observers, two French and two English, took part in the work as in 1888; three of them were the same as before (Colonel Bassot, Commandant Defforges, and Mr. Turner), but Mr. Hollis replaced Mr. Lewis, whose special attention was required in the Time department. The plan of operations adopted in 1888 was only modified in the following particulars: two clocks were used instead of one, at each end of the line, and all the clocks were plaçed in rooms kept at nearly constant temperature. The Sidereal Standard was used by the English observer at Greenwich throughout. The English observers used the small chronographs procured for the Montreal longitude, with one pen only, thus avoiding the troublesome correction for parallax of pens.

In the first part of the operations, Commandant Defforges and Mr. Turner were at Greenwich, Colonel Bassot and Mr. Hollis at Paris. Signals were exchanged on 7 nights, on 4 of which clock error was determined at Greenwich and on 6 at Paris.

In the second and third parts the observers were interchanged; signals were exchanged on 11 nights, observations of stars for clock error being obtained on 8 of these, both at Greenwich and at Paris.

In the fourth part, the observers returned to their original stations. Signals were exchanged on 11 nights, clock errors being determined on 5 nights at Greenwich and on 9 nights at Paris.

The preliminary discussion of the English results for the difference of longitude between the Greenwich transit circle and Cassini's meridian is now complete, the mean of 25 practically independent determinations, after correcting for personal equation, being $9^{m}\ 20^{s}.82$. The value found in 1888 by English observers was $9^{m}\ 20^{s}.85$.

In July Professor McLeod came to Greenwich to discuss the first stage of the operations for the longitudes Montreal—Canso—Waterville—Greenwich. It appeared that the cable signals were for practical purposes as accurate as those over the land lines; and thus the chief difficulties of the work are, as in other cases, simply those of absolute time determination.

The second stage of the operations was commenced on August 16, and completed on September 16. It consisted of two parts, in the first of which the observers at Montreal, Canso, Waterville and Greenwich were Mr. Turner, Mr. Klotz, Mr. Hollis, and Professor McLeod respectively; signals being exchanged on every night (except in one or two cases of accidental interruption) from August 16 to August 30, and clock errors being obtained at the several stations on 8, 6, 6 and 11 nights respectively.

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* Extracts from the Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich. Read June 3, 1893.

The observers were then interchanged to the following order:— Mr. Klotz, Mr. Turner, Professor McLeod, Mr. Hollis. Signals were exchanged each night from September 3 to September 16, and clock errors were obtained on 6, 12, 6, and 10 nights respectively.

The total number of nights on which there was complete connection by signal between Greenwich and Montreal was 20.

The sidereal observations made by the Greenwich observers, and the signals, are completely reduced; but we have not yet received from Montreal the results of the time determinations by Professor McLeod and Mr. Klotz.

In the year ending 1893 May 10, photographs of the Sun have been taken with this instrument on 180 days, and of these 410 have been selected for preservation, besides 22 photographs with double images of the Sun for determination of zero of position.

The photographic telescope presented by Sir Henry Thompson, which has been mounted on the Lassell equatorial, has been in regular use as a photoheliograph since January, 1893, and photographs of the Sun have been obtained with it on 89 days, of which 158 have been selected for preservation. In all with one photoheliograph or the other a record of the state of the solar surface has been secured on 220 days during the year. A new enlarging lens by Messrs. Ross & Co., which appears to be very free from distortion, was fitted to the Thompson photoheliograph on December 13, and has been used regularly since for the eight-inch photographs of the Sun.

For the year 1892 Greenwich photographs have been selected for measurement on 197 days, and photographs from India and Mauritius (filling up the gaps in the series) on 165 days, making a total of 362 days out of 366 on which photographs are available.

The solar activity has been fully maintained throughout the past year, though no single spot has appeared equal to that of 1892 February. The mean daily spotted area for 1890 was 100, for 1891, 566, and for 1892, about 1230.

This great development of activity seriously increases the work of the department; as an example it may be mentioned that 35 books of the form used in reducing the spot positions were required for the years 1891 and 1892, while in the whole 17 years preceding, for which photographs have been measured, only 85 books had been used, 39 of these having been used in the *three* years 1882-4 of the last maximum. Notwithstanding this increase in the work, the measures and reductions are in a more forward state than at the date of the last Report. The measures of positions and areas for 1891 are now passing through the press, and the Spot Ledgers for that year are prepared for press. The photographs have been measured and reduced up to 1993 January 13, the reductions examined up to 1892 October 27, and the copy for press written up to 1892 September 10. But to cope with this unexpectedly severe Sun spot maximum it has been necessary to largely increase the number of computers employed on this work, and a further addition will probably be required if, as seems likely, the solar activity continues to increase.

Astro-Physics.

ON THE BRIGHT BANDS IN THE PRESENT SPECRUM OF NOVA AURIGÆ*

WILLIAM HUGGINS AND MRS. HUGGINS.

Some few prefatory words are called for in explanation of the partial incompleteness of the present communication.

A considerable brightening, from below the 14th magnitude to above the 10th magnitude, was found to have taken place in the Nova when it was re-observed in the early part of August, 1892, and to be accompanied by a modification of its spectrum, apparently analogous to a similar change in the spectrum of Nova Cygni in 1877, since the observations we made of the star on March 24, 1892, when it had fallen to nearly the 11th magnitude.†

In consequence, however, of the removal of the eye-end of the telescope to the workshops of Messrs. Troughton and Simms for the attachment to it of the mounting for a fine Rowland grating by Mr. Brashear, we were without the means of observing the star and its spectrum during the whole of the autumn and the early winter. It was not until the beginning of the year that the new spectroscope was mounted in our Observatory, and then, from some instrumental causes of delay and from a prevalence of bad weather, we were not able to observe the spectrum of the Nova until the night of February 1.

Before this time the altered appearance of the spectrum of the Nova had been observed at several observatories, and its spectrum had been described as consisting mainly, in the visible region, of a bright line in the orange, of the two nebular lines,and of the hydrogen line at F.

As soon as we directed the spectroscope to the star, we saw at once, even with one prism, that the two principal bright bands which had been described as the "nebular lines" were in strong contrast with these, not single lines but broad bright spaces, diffused at the ends and irregularly bright, which we suspected to be groups of bright lines.

On February 8 we observed these bright spaces with the 4-inch grating of 14.438 lines to the inch, using the spectrum of the second order. The collimator and the telescope have each an

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* Read before the Royal Society. Communicated by the authors.

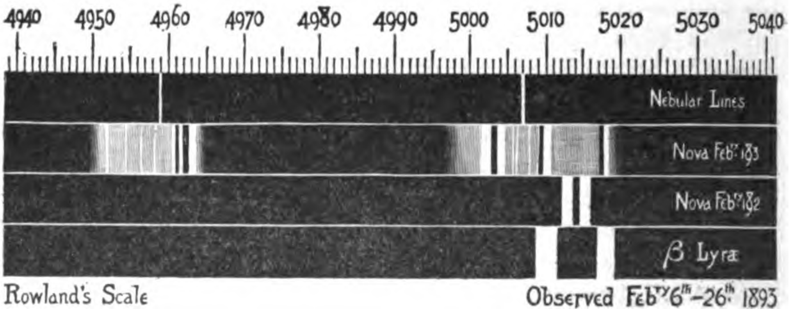
† *Roy. Soc. Proc.*, Vol. 51, p. 492.

aperture of 2 inches, and the spectrum was viewed under a magnifying power of 23 diameters. Our suspicion was then confirmed, the bands being clearly resolved into groups of bright lines upon a feebly luminous background.

On February 26, micrometric measures were begun of the positions of the constituent lines of the groups, when unfortunately we discovered that in consequence of flexure in one part of the instrument, a shifting of the micrometer webs relatively to the lines of the spectrum was liable to take place, and so make the measures uncertain to about as much as 2 tenth-metres when the spectrum of the second order was in use.

The cause of the want of rigidity of the instrument in this respect made it necessary that the spectroscope should go back to Messrs. Troughton and Simms' workshops; and then, from unavoidable delays and the coming in of the Easter holidays, it was not until the second week in April that the spectroscope was again in position for use; but by this time the Nova was too far past the meridian for satisfactory observations to be made upon its spectrum.

Our opportunities of working upon the spectrum of the star were thus absolutely restricted to the few fine nights between February 1 and February 26; and further our observations of the positions of the lines are, for the reason we have mentioned, affected with a possibility of error which may be as great as 2 tenth-metres, though it is probable that the positions given in the diagram are not actually in error to as much as half that amount.



For the same reason the resolution of the minor features of the groups has not been worked out with the completeness which was well within our instrumental means, if the number of fine nights had not been so limited, for on some of the nights on which observations were attempted the sky was not clear enough from thin haze for the resolution of the more difficult features of the spectrum of a star of between the 9th and 10th magnitude.

Still, notwithstanding the comparatively incomplete state of our observations, which we greatly regret, we do not hesitate to consider them of sufficient importance, bearing as they do upon so remarkable a phenomenon as would be the change of a star into a nebula, to justify us in communicating them to the Royal Society.

The spectroscope is provided with a 4-inch Rowland grating by Brashear, and a prism of dense flint of 27°, silvered on one face, which can take the place of the grating in the grating box.

As we have already stated, the observation of the Nova with this prism showed the bright "lines" broad and irregularly bright, and raised the suspicion in our minds that they were probably groups. They were observed more or less successfully with the grating, usually with an eye-piece magnifying 23 diameters, on February 8, 10, 11, 16, 17 and 26.

1. *Brighter Group near the Position of the Principal Nebular Line.*

The separate results of our more favourable observations of this group on the different nights are put together in the accompanying diagram. In addition, however, to the details drawn in the diagram, at several very favourable moments of seeing, we had distinct and undoubted glimpses of finer lines in the spaces between the brighter ones, of which some only are given in the diagram. For this reason the diagram must be regarded as an incomplete representation of the group, though showing accurately its main features and general character.

The group, as shown in the diagram, extends through a little more than 15 tenth-metres, and consists of lines more or less bright upon a feebly luminous background, which can be traced to some distance beyond the lines at both ends of the group. The more prominent features are: two lines, the brightest in the group and about equally bright—but the more refrangible one rather the brighter—which form the termination of the group towards the blue; a line nearly as bright about the middle of the group; and a third prominent line at the end of the group towards the red.

We have little doubt, though we hesitate to state it positively, that the space between the two brightest lines, that on the blue side of the bright line in the middle of the group, and the spaces on the blue sides of some others of the lines were darker than the faint luminous background, in which case we should have to do possibly with lines of absorption of the same substances shifted towards the blue. A few only of the finer bright lines which were occasionally glimpsed between the more brilliant lines have been put into the diagram.

The pair of bright lines at the termination of the group towards the blue makes this the brighter end of the group, which does not however, as a whole possess any of the usual features of a fluting.

On February 10, the micrometer webs were placed so as just to include the bright lines of the group, but not the faint background which at the clearest moments could be traced for some distance, especially at the blue end of the group. The instrument remained untouched, and the position given in the diagram is that found from the places of the micrometer webs upon the solar spectrum, on Rowland's scale, as observed on the following morning.

On the 26th, measures of this group were made relatively to the position of the principal line in the nebula of Orion; these gave also almost exactly the same position in the spectrum for the group, but, as we have already stated, all these measures are unfortunately liable to a small error from the possible flexure, at that time, of a part of the instrument.

The mean of Mr. Campbell's measures at the Lick Observatory, during the period of our observations, from February 10 to February 27, gives λ 5006 for the middle of the band. He remarks: "In any discussion of these observations it is necessary to take into account the difficulty of accurately locating the centre of a line so broad and diffuse as this one is."*

In another place Mr. Campbell says: "The line is at least 8 tenth-metres broad and the edges very diffuse."†

These observations would be brought into accordance with our own, so far as relates to the length and the position of the band, if we suppose Mr. Campbell to have observed, only the more refrangible and much brighter half of the whole group.‡

The probable analogy between the Nova and the remarkable variable star *β* Lyræ, in the spectrum of which also, we have to

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* ASTRONOMY AND ASTRO-PHYSICS, May, 1893, pp. 418, 419.

† *Publ. Ast. Soc. Pacific*, vol. 4, p. 246.

‡ Professor Campbell also says: "On August 30 the line was suspected to be double, and the grating measures of that night refer to a point midway between the two condensations. On September 7 the measures refer to a point of maximum brightness slightly less refrangible than the centre of the line."—ASTRONOMY AND ASTRO-PHYSICS, Oct., 1892, p. 718.

do apparently with bright and dark lines of the same substances, though not in all cases identical with those of the Nova, in motion relatively to each other, which we ventured to point out in our former communication on the Nova,* has been recently greatly strengthened by the photographic observations of *β* Lyræ at different stages of its periodic variations by Dr. Bélopolsky at the Observatory of Pulkova.

In some of his photographs, especially in one taken shortly after the star's second maximum, bright lines come out near the positions of the bright groups of the Nova which are now under discussion. As the scale of Dr. Bélopolsky's photographs is much smaller than that of our diagram, we felt some hesitation in attempting any identification of his lines with those of the Nova. At our request, Dr. Bélopolsky has been so kind as to put into our diagram the two brightest of the lines of *β* Lyræ, as they appeared shortly after a second maximum, which fall within the brightest group of the Nova, and which, indeed, may be identical with two of the lines in the Nova. It may, however, be thought that the lines of *β* Lyræ suggest that they are independent bright lines rather than members of a group such as that of the Nova.

Whatever may ultimately be found to be the truth, there can be no question as to the probable high significance of the remarkable analogy which exists between the changes which take place in *β* Lyræ and those which have been observed in Nova Aurigæ.

The two other spectra in the diagram represent respectively the position and character of the two nebular lines, and the position of the bright double or multiple band which was so brilliant in this region of the Nova in the beginning of last year.

2. *Bright Group near the Position of the Second Nebular Line.*

Not anticipating that our opportunities ofobserving were to be so soon cut off, we gave our attention chiefly to the brighter group, intending, after we had completed our observations and measures of it, to attack seriously the second group.

However, on nearly all the nights we observed we gave some attention to this group, which, from being fainter, is more difficult to resolve, though on the clearer nights it was fairly well seen with the grating.

Generally, the group may be described as of the same order as the brighter one, consisting of bright lines and possibly of some absorption lines upon a feebly illuminated background.

We have endeavoured to represent in the diagram as truthfully as we can the best views we obtained of this group; during one

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* *Roy. Soc. Proc.*, vol. 51, p. 494.

or two exceptional moments of good seeing we thought that we glimpsed finer bright lines in the spaces between. Indeed, the group may consist of a close grouping of bright lines.

For the same reasons, fewer measures were attempted of this group, and its position was less accurately determined, but neither the constitution of the group as represented in the diagram nor its position can, we think, be much in error.

We were also unable to work upon the bright line in the orange, and to do more than satisfy ourselves, by a direct comparison, that the line about F was really the hydrogen line in that region.

General Conclusions.

It need scarcely be said that no contrast could well be more striking than that which these extended groups of lines form with the two narrow and defined lines in the spectrum of the great nebula in Orion.

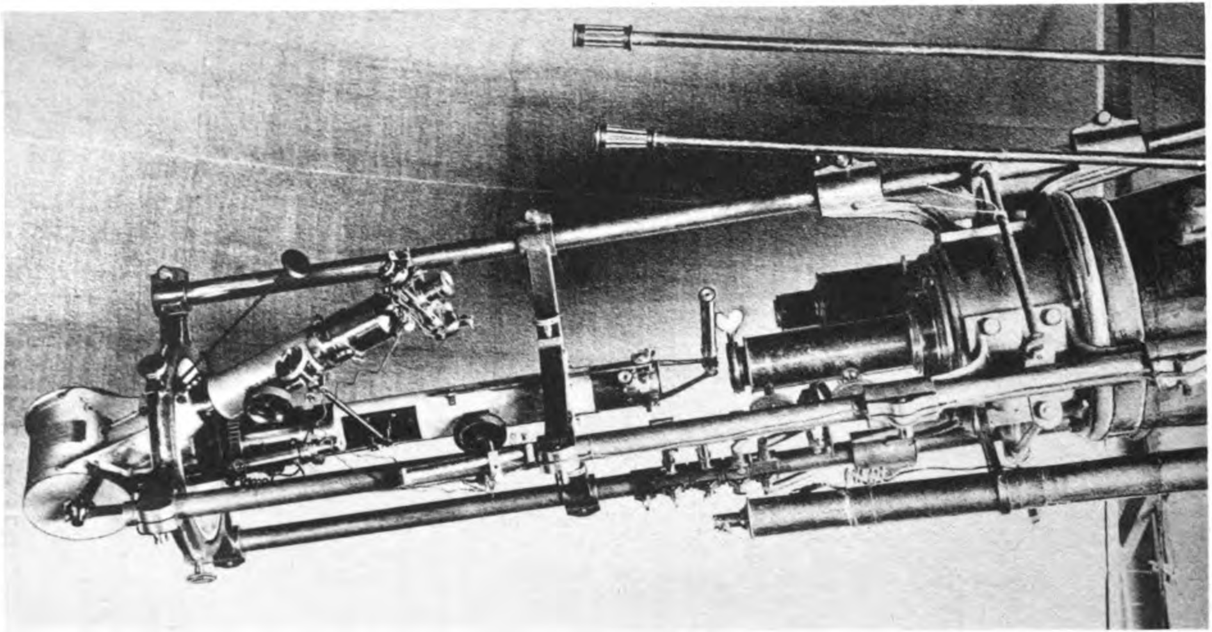
It is difficult to suppose that we have to do with the same substance or substances, whatever they may be, which produce the nebular lines, even if we imagine very different conditions of temperature, or even allotropic conditions.

In the laboratory, allotropic changes are not usually accompanied by new groups, or lines at the positions of the characteristic lines of the substances in their original state.

We wish to speak at present with great reserve, as our knowledge of the Nova is very incomplete, but we do not regard the circumstance that the two groups of lines above described fall near the positions of the two principal nebular lines as sufficient to show any connection between the present physical state of the Nova and that of a nebula of the class which gives these lines.

Influenced by the analogy between some of the changes in the spectrum of the Nova and those which are associated in the spectrum of β Lyræ with the variation of its light, and also by other reasons which we pointed out in our former communication, we are still strongly inclined to take the same view which we there ventured to suggest, namely, that in the outburst of the Nova we have not to do mainly with cold matter raised suddenly to a high temperature by a collision of any form but rather, for the most part, as was suggested by Dr. Miller and myself in 1866 in the case of the first temporary star examined with the spectroscope, to an outburst of existing hot matter from the interior of the star or stars; indeed, to phenomena similar to, but on an immensely grander scale than those with which we are familiar in the peri-

PLATE XXXIV.



THE TULSE HILL SPECTROSCOPE.

odic greater and lesser disturbances of the Sun's surface.

Such grand eruptions may well be expected to take place as stars cool, and if in two dull and comparatively cool stars such a state of things were imminent, then the tidal action due to their near approach might be amply adequate to determine, as by a trigger action, such eruptions.

Under such conditions, fluctuations of brightness and subsequent partial renewals of the eruptive disturbances might well take place.

THE MODERN SPECTROSCOPE.

VIII.

The Tulse Hill Spectroscope.[*]

WILLIAM HUGGINS.

This instrument was designed primarily for the purpose of mounting upon the 15 inch Refractor belonging to the Royal Society, a fine 4 inch Rowland grating which was furnished to me by Mr. Brashear.

A condition of fundamental importance in the adaptation of the spectroscope to the telescope is that the instrument shall remain perfectly rigid in all its parts relatively to each other, and also to the optical axis of the telescope, in all positions of the telescope. It appeared to me that this condition would be most certainly secured by making the spectroscope complete and rigid in itself, independently of its attachment to the steel tubes, by which it is supported. The spectroscope if removed from the telescope would remain a complete and rigid instrument.

The firm attachment of this spectroscope to the telescope is carried out by means of three steel tubes 1⅜ inch external diameter, which slide in three long brackets strongly bolted to the iron eye-end of the steel tube of the telescope. These tubes, as can be seen in the photograph, are further held together and formed into a stiff supporting cage by two iron ring brackets through which they pass. The ring-bracket near the ends of the tubes supports the heavy part of the spectroscope, consisting of the grating and prism box; the other ring-bracket supports the collimator near the slit end, and strengthens the tube-cage near the middle of its length.

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[*] Communicated by the author.

By means of adjusting screws in these ring-brackets the axis of the collimator can be brought into line with the optical axis of the telescope. The other necessary adjustments are also provided for. . By the large milled head on the top of the collimator, the spectroscope, as a whole, can be moved so as to bring the slit to the focal plane of the object glass for the part of the spectrum under observation; and a fine graduation on the sliding tube enables this adjustment, and also any similar adjustment that may be required for changes of temperature to be found at once after the necessary data have been obtained. The adjustment of the collimator lens can be made by a smaller milled head. By an arrangement, which explains itself in the photograph, the collimator and telescope can be focussed simultaneously.

The collimator, and the telescope, fixed at an angle of 25°, are firmly attached to the grating-box, and are further secured from relative flexure by a gun-metal collar fitting into the iron ring-bracket.

The grating is mounted in an air tight metal case, provided with shutters to open when it is in use. This case slides into the box against a fixed point so as to secure the grating always taking up the same position. A prism of 37° silvered on one face, similarily mounted can take the place of the grating when small dispersion is required.

The grating, or prism, is moveable about the axis of the box, by a rod which is placed conveniently for the hand of the observer. At the top of the box, which is strengthened internally by metal compartments, a sector is fixed on the moveable axis, which is graduated on silver, and is read by a small telescope. The graduated edge of the sector, which can be illuminated by a small incandescent lamp, is divided into spaces of 5′, and reads by the aid of the vernier to 10″.

The telescope of the spectroscope is provided with a micrometer by Troughton and Simms, the fine webs of which are very successfully illuminated simultaneously from both sides from one small incandescent lamp, on an original plan devised by them. The amount of illumination can be varied by means of a small resistance coil to suit the object under observation. With the feeble illumination which is necessary for most celestial objects, it is not easy to read the number of whole revolutions of the micrometer screw, in the usual way, from the teeth of the comb. A simple form of a revolution-counter is geared into the outer rim of the micrometer head, and turns with it without sensible friction. The micrometer heads and their revolution-counters can be illuminated at pleasure by means of two small moveable incandescent lamps suitably placed above them. The micrometer-screw has 100 threads to the inch; and when the second order of the grating, ruled to 14,438 to the inch, is in use, about $\frac{23}{1000}$ of a revolution are equal to one tenth-metre.

The collimator and telescope have thin cemented lenses of 2¼ inches diameter; that of the collimator is provided with a diaphragm reducing it to 2 inches, which is its effective aperture; as the collimator has a focal length of 24 inches, and the object-glass of the telescope a ratio of $\frac{f}{12}$. The telescope of the spectroscope has a focal length of 18 inches, and is provided with four eye-pieces magnifying respectively 12, 18, 22 and 29 diameters.

For photography the eye-part of the telescope can be replaced by a camera, and the whole instrument rotated through 90°, so as to bring the length of the slit in the direction of the star's motion.

The grating-box can be uncoupled from the collimator and removed from the supporting iron ring, and replaced by a battery of glass prisms, the same telescope and micrometer, or photographic lens and camera, being then attached.

A novelty in this instrument, which will be seen at once to be one of great practical importance, consists of a simple but very effective arrangement by which a star can be brought at once, and kept steadily, within the jaws of the slit. For my primary photographic work on the spectra of the brighter stars, I devised in 1875 a method of bringing and keeping a star within the slit, which is figured and described in my paper "On the Photographic Spectra of the Stars," (*Phil. Trans.* 1880 p. 673):

"A round thin plate of polished silver, 1½ inch in diameter, with a narrow opening in the middle rather longer and wider than the slit itself, was fixed over the slit of the spectroscope. This forms a plane mirror, and when the telescope has been brought approximately into position by its finders, the bright image of a star is seen somewhere upon the plate by looking into a Galilean telescope fixed in the place of the eye-piece of the Cassegrain telescope. Now if at the same time artificial light is thrown upon the plate, it becomes itself visible and thus the opening in it, and the slit within the opening can be distinctly seen at the same time as the image of the star as a bright point upon it. By the aid of this arrangement there is no difficulty in bringing the star's image by the slow motion handles of the equatorial readily, and with precision upon any part of the slit. As the position of the star's image even upon the slit itself can be seen, the image being somewhat wider than the slit and therefore not wholly lost within it, it is possible to keep the star in view upon the slit during the whole time the photograph is being taken; and to correct instantly by hand any small departure of the star's image from its proper place upon the slit."

Some improvements, and modifications of the original plan have been made to suit the conditions of a spectroscope applied to a refracting telescope. Slit-jaws of speculum metal have been substituted for the silver plate used in 1875. This metal answers the purpose admirably as it receives and maintains a high polish, and can be fashioned to take very smooth and true edges for the slit.

If the polished surfaces of the jaw-plates were in a plane perpendicular to the optical axis of the telescope, the light after reflection would return upon its path. The plane in which these surfaces lie is, therefore, slightly inclined so as to throw the reflected light sufficiently to one side of its original direction to be caught by a suitably formed reflecting prism placed just outside the converging rays from the object-glass. This prism is provided with a suitable optical arrangement of some magnifying power, and is shown in the photograph, in position for use.

At night, when the telescope is directed to the heavens, if the eye is placed at this reflecting eye-piece, a field of stars of about 5′ in diameter is seen together with the slit crossing it. Very often the faint illumination of the sky is sufficient to enable the slit to be seen, but if necessary, a feeble artificial light can be thrown upon the polished surfaces, so as to make the slit visible, but without interfering with the visibility of the images of even faint stars. It is obvious that by means of this arrangement it is quite easy to bring, and also to keep steady a star image upon any part of the slit. In the case of suitable double stars wider than about 3″, component images are seen well apart, and either of them can with ease be brought and kept within the slit-jaws. So also in the case of planets and nebulæ there is no difficulty in selecting any small part of one of these objects for separate spectroscopic examination.

This reflecting eye-piece is hinged, and when not in use can be turned down out of the way to give room for a large diagonal eye-piece for viewing celestial objects directly, without removing the spectroscope from the steel tubes.

The slit is also provided with the usual reflecting eye-piece, which can be pushed in behind it. I pointed out in my paper of 1879 (*loc. cit.*) that in photographing the spectra of the stars the necessary breadth can be most conveniently obtained by the plan now universally employed, of giving a small motion to the star's image in the direction of the length of the slit. For eye observations it is still necessary to have recourse to cylindrical lenses. For a great number of years I have minimised the inconveniences which such lenses introduce by using the plano-concave instead of the usual plano-convex form.

Perhaps the least objectionable way of using them, is to have three, or more, of different cylindrical curvatures fitted into a small brass slide, which goes immediately in front of the eye-lens, and fits equally the different eye-pieces. The lens giving the most suitable breadth can be brought into use, and if it be of concave form, without in the least disturbing the focal adjustment of the eye-piece.

If it be preferred to place the cylindrical lens before the slit, the advantage in respect of light will be seen to be in favor of the plano-concave form.

The arrangement for comparison spectra is attached to one of the rods, a reflecting prism of 90°, sending the light upon the small moveable prism immediately in front of the slit. The optical arrangement is such as to completely fill the lens of the collimator with the light which furnishes the spectrum for comparison.

I cannot refrain from expressing my admiration of the great rigidness of every part of the apparatus, as well as of the extremely fine definition both when the prism and the grating are in use; for which the highest credit is due to Messrs. Troughton and Simms; and also to Mr. Brashear for the high qualities of the grating.

I ought to add that a second spectroscope, containing some new points of importance is now in course of construction for use with the 18-inch Cassegrain telescope, for the photography of the ultra-violet spectra of celestial objects.

PHOTOMETRIC OBSERVATIONS OF THE PLANETS.[*]

EDWIN B. FROST.

An important contribution to the rather neglected subject of planetary photometry has been made by Professor G. Müller in No. 30 of the Publications of the Astro-Physical Observatory at

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[*] Communicated by the author.

Potsdam under the title " Determinations of the brightness of the larger planets and several of the asteroids."

The observations included in the memoir were made exclusively with the Zöllner photometer, and extend over a period of eight years, only such evenings being utilized as were meteorologically above suspicion.

The object of these researches was to test the correctness of the various theories of the variation of brightness of planets with their change of phase; to discover analogies between the different planets in respect to their reflecting power: and to obtain data for the investigation of certain closely related subjects, such as the constancy of the light emitted from the Sun, and the existence of an absorbing medium within the space occupied by the solar system. We may perhaps best state the results on these two points at once. Since the brightness of the planets is measured by comparison with stars, it is plain that any periodic variations in the brightness of the Sun—so difficult to determine directly—will be mirrored in the measured brightness of the planets, which moreover should all be correspondingly affected. Now on combining his results into yearly means, Müller finds evidences of such variation, particularly in the case of Jupiter, which cannot be attributed to the uncertainty of the measurements. This could be accounted for by a periodic change in the transparency of the Jovian atmosphere, but similar though less pronounced variations in the case of Mars, Saturn and Uranus give weight to the former interpretation.

Müller finds that if an absorption occurs at all in the space within the solar system, the density of the absorbing medium must be considerably under one thirty-millionth of that of the Earth's atmosphere at sea-level.

A first requisite of these investigations was an exact knowledge of the magnitudes of the comparison stars used. (A star near the planet, and of as nearly the same magnitude as possible, was employed for comparison). Accordingly the magnitudes of 14 standard stars brighter than the 2d mag., used with the brighter planets, were very carefully compared, pair-wise, and then combined and connected all together. The brightness of the pole star was taken as 2.15, so that the scale is the same as that of the H.P. 42 fainter stars employed for comparison with the fainter planets were treated in a similar manner, so that an independent catalogue of the magnitudes of 56 stars was obtained, which in most cases quite fully confirmed the results of the H.P.

The probable error of the value for a star of the brighter group was about $\frac{1}{30}$ mag., and for the others about $\frac{1}{20}$ mag.

In these measurements the correction for atmospheric extinction was taken directly from a table previously made from a great number of observations at Potsdam. Müller considers this procedure more satisfactory than that adopted by Pickering of obtaining the co-efficient of extinction for each night, as the data for its determination must then be few, and the practice of utilizing only the clearest nights makes in his opinion the tabular values more reliable.

The results communicated in the memoir may be briefly summed up as follows:

The formulæ of Euler, Lambert and Seeliger are all inadequate to express completely the variation of brightness of a planet with phase, though Seeliger's theory is the best from a theoretical as well as practical stand-point.

The empirical expression, found by Müller for the brightness of the planets at any time are as follows, (α being the angle of phase and everything being expressed in magnitudes).

Mercury	$B = -0.901 + C + 0.02838\,(\alpha - 50) + 0.0001023\,(\alpha - 50)^2$
Venus	$-4.707 + C + 0.01322\alpha + 0.0000004247\alpha^3$
Mars	$-1.787 + C + 0.01486\alpha$
Jupiter	$-2.233 + C$
Saturn	$0.877 + C + 0.0436\alpha - 2.5965 \sin A + 1.2526 \sin^2 A$
Uranus	$5.863 + C$
Neptune	$7.661 + C$
Ceres	$6.909 + C + 0.0423\alpha$
Vesta	$6.006 + C + 0.0266\alpha$

For the first two planets $C = \frac{1}{0.4} \log \frac{r^2 \Delta^2}{r_0^2}$; for the others

$$C = \frac{1}{0.4} \log \frac{r^2 \Delta^2}{r_0^2 (r_0 - 1)^2}$$

where r is the distance from the Sun to the planet at the time and r_0 is the mean distance, and Δ is that from Earth to planet. The minus sign indicates a negative magnitude, the object being brighter than the 0 mag. In the case of Saturn the angle A is the elevation of the Earth above the plane of the ring.

The variations of brightness of Mercury do not at all agree with theoretical values, but correspond very closely with Bond's observations of the Moon. Müller concludes that Mercury has no atmosphere or only a very slight one. (It will be remembered that the spectroscopic evidence of such an atmosphere is by no means conclusive). He does not share the optimistic views of some that the knowledge of the substances causing the reflection may be gained from the comparison of the light-curve of the planet with the optical behavior of diffusely reflecting terrestrial substances.

The observations show no connection between the brightness of a planet and its axial rotation, and no variation of the asteroids such as to indicate a rotation.

The relative albedos of the various planets in terms of that of Mars are found to be as follows, with Zöllner's values added for comparison:

	M.	Z.		M.	Z.
Mercury	0.64	0.43	Saturn	3.28	1.87
Venus	3.44	2.33	Uranus	2.73	2.40
Mars	1.00	1.00	Neptune	2.36	1.74
Jupiter	2.79	2.34			

In conclusion Müller deduces the radii of the 17 minor planets which he observed, on the two assumptions, first (and most probable) that their albedo is the same as that of Mercury, and second, that it is the same as that of Mars. We cite a few of the values, according to the two hypothesis:

	I	II
Ceres	R = 475 km	R = 379 km
Pallas	354	282
Vesta	473	377
Hebe	159	127

The investigations communicated in the memoir are a part of an extensive photometric campaign which has been in progress for some time at Potsdam. The accuracy attainable with the Zöllner photometer and the well-known skill and thoroughness of the observers justify the interest with which the appearance of further results will be awaited.

ON CERTAIN TECHNICAL MATTERS RELATING TO STELLAR PHOTOGRAPHY.*

MAX WOLF.

The Change of Sensitiveness in Dry Plates.

In no kind of photographic work is a knowledge of the sensitiveness of dry plates of such importance as in stellar photog-

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* The following is a free translation of an article in Eder's Jahrbuch für Photographie und Reproductions-technik, by Dr. Max Wolf, of Heidelberg, whose admirable work in stellar photography is so well known. We do not think that

raphy. Generally, a photographer has merely to remove the cap of his lens, replace it, and the operation is complete. If the exposure proves to be too short he gives another and longer one; or he takes at once two plates with different exposures.

With the astronomer the case is very different. For him the chief part of the work lies between the opening and closing of the shutter, for in the interval he must keep his camera directed with the most careful attention, often for hours, to the moving stars which the imperfect clockwork of his apparatus will only approximately follow. What that means, only he who has tried it can tell. It is easy to imagine that under these circumstances a very sensitive plate is welcomed by the astronomer. The tedious work of exposure is proportionally shortened.

But it is not a pleasant experience to give an eight or nine hours exposure to what is believed to be a highly sensitive plate, and then to find on development that the whole work has been thrown away, because the plate was really a quite insensitive one. The photographer who has had this experience repeated several times, (as I have), very soon learns to become cautious. The only reliable test of sensitiveness, however, as I may here remark, is comparison by actual exposure to stars, the ordinary sensitometer tests being much too uncertain.

Special caution is necessary in dealing with fresh plates. In the early part of my work I always noticed that new plates received from the makers were uniformly less sensitive than the previous ones, and that it was necessary to expose them a much longer time, so that it almost seemed as if the manufacture of dry plates was retrograding. The plates which I principally used were those of Lumière, Schleussner, Beernaert, and Wratten and Wainwright. They all showed this apparent decrease of sensitiveness, the Lumière plates most strongly, those of Schleussner in a less degree. The peculiarity is so strongly marked that during the last winter I was hardly able to obtain the same objects on a new lot of Lumière plates that I had previously obtained with the last plates of the same make, even with a threefold greater exposure. Stars and nebulæ which I had photographed easily in one hour. hardly appeared on the new plates after an exposure of three hours.

I had indeed known earlier than this, that plates changed some-

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the difficulties described by Dr. Wolf in connection with lenses have been generally met with in this country, probably for the reason that lenses designed for stellar photography have almost always been made by astronomical opticians, who are familiar with the precautions which must be observed in mounting large telescope objectives.

what in sensitiveness when stored, but I could hardly expect that the change would amount to so much as a threefold increase; and yet it was so. After five months the new Lumière plates, at first so slow, were as sensitive as the preceding ones, and exceeded in sensitiveness all my other plates. A similar change took place in those of other makers. The orthochromatic plates seemed to have a smaller tendency to changes of this kind.

The sensitiveness does not by any means increase indefinitely with the time. On the contrary, it soon reaches a maximum, which persists for some time, and after this the sensitiveness diminishes. Hence it became a rule to test each kind of plate, in order to determine when it was in its most sensitive condition.

For Lumière plates this time has been found to be from five to seven months after manufacture. By taking advantage of this fact, much can be gained; sometimes, as I have said, an increase in sensitiveness of three or four times. Whether the period of ripening is always quite the same under similar processes of manufacture is somewhat doubtful, and the question must be left undecided.

From the foregoing the astronomer may take warning never to assume that plates made from the same emulsion are equally sensitive, if they are used at different times. The sensitiveness of the emulsion differed, in the cases mentioned, according to the time when the exposure was made. For the same reason it is also very difficult to determine beforehand what exposure should be given in order to obtain stars of a certain magnitude. It is quite impossible to do this, (leaving out of the question changes in the transparency of the air), without taking into account the age of the plates.

On the mounting of large photographic objectives.

The proposition may be stated, that for testing a photographic objective there is no method in any way so satisfactory as that of photogarphing stars. The faults of the objective are brought out conspicuously, so as to be visible at a glance, as they are by no other method.

It is especially astonishing to see how small the flat field is, which the objective will define sharply. Portrait lenses, as well as wide-angles and aplanatics, have a really quite frightfully small field free from aberration. If a four-inch portrait combination of the best make will define perfectly a space 2¼ inches square without a stop, it must be regarded as performing very satisfactorily. A four-inch Euryscope by one of the best opticians, without a stop, does not by any means cover a plate 3½ × 4¾ inches; and with an otherwise perfect five-inch aplanatic lens I could hardly exceed a plate of this size. So with the other qualities of objectives, and I will show at another time how the spherical aberration of an object-glass, in particular, can be determined by this method with great accuracy. I wish here to speak of another defect of object-glasses, which can be easily corrected, and which nevertheless, although it is very detrimental to sharpness even in ordinary photography, has hitherto received but little attention. I mean the distortion of an image due to pressure on the lenses by the cell in which they are mounted.

For my experiments on this subject I had a number of lenses, 2½, 3, 4 and 5 inches in diameter, by the best makers, and I must say that all, without exception, showed this defect, in most cases very strongly.

Last year, (for I will relate here the history of my sorrows), after I had used a number of smaller instruments for some time, I came into possession of a five-inch aplanatic lens, and mounted it on my refractor. The flange of its mounting was provided with screws, by which it was ordinarily attached to the camera. On my refractor there is, however, a strong brass bracket (1½ to 2 in. thick and weighing 30 lbs.), and on the front turned surface the flange of the mounting was secured by its screws, while the camera was fitted to the other side. The five-inch lens in its cell was then screwed into the mounting. After focusing, I tried it on the stars and obtained atrocious images.

With a perfect objective the photographic image of a star is, as is well known, a very small circular disc, which becomes larger and larger as the time of exposure is prolonged. Instead of small circles I obtained images which had an irregular appearance. At first I thought that the principal cause of these distorted images must be imperfect centering of the lenses, and made a series of investigations in this direction. I photographed a star several times with different adjustments for focus, and in this way obtained images, representing cross-sections of the cone of rays from the lens at different places, which were not circular, but angular, and quite irregular in shape. These experiments were very interesting, but still they did not lead in the right direction. The maker of the aplanatic lens, to whom I sent plates and copies, afterwards centered the lens in the most exact manner. I myself placed the plate exactly at right angles to the optical axis, but all in vain. It very soon appeared, however, that turning the lenses in their cell changed the position of the irregularities in the image. This at first led me again to regard imperfect centering as the cause of the defect, and I was much perplexed to know what I should do next, inasmuch as not the slightest error of centering could be detected by optical methods.

I now changed the object of the investigation; I tried other objectives in the same way, taking star photographs with a four-inch portrait combination of known excellence, by a Parisian maker, a 2½-inch aplanatic made in South Germany, and a four-inch Euryscope. In this way I was soon led to the cause of the bad images. Not that these lenses did not have the same defects; on the contrary, the portrait lens depicted the stars as blurred, but still easily recognizable hexagons, the aplanatic lens as triangles, and the Euryscope as distorted pentagons. Now the mounting of the portrait lens was secured with six screws, that of the aplanatic with three, and that of the Euryscope with five screws.

I now took the five-inch aplantic again, and screwed tightly home the five screws of its mounting. (Before, they were only loose, and strips of felt had been placed under them.) The result was that I obtained beautiful five-pointed stars.

But even when I left the screws so loose that the mounting of the aplanatic could rock, the points of the image could still be recognized, although they were greatly reduced in strength. It further became evident that some other distortion must be present, superposed on that caused by the screws, which obscured the latter when the screws were loose. It was for this reason that I was not at first able to recognize the fact that the distortion was caused by pressure on the glass.

In order to be certain of the extent to which the bending of the lenses was produced by the strain of the screws, a very thick mounting (a brass ring more than an inch thick) was made for the lenses, and secured loosely to the bracket with three screws, which passed through three slight projections, so that the mounting was supported at only three places. The lenses of the aplanatic were so much loosened in their cells that they could be made to rattle, in order to free them from any strain. The result was that the stars, aside from the distortion previously referred to, were triangular.

The cells of the lenses were then strengthened by the maker. I hoped further that by putting a large number of screws in the mounting, the angles of the image could be distributed, and would perhaps no longer be apparent. But the strengthening of the cells of the glasses was of no avail; six screws give six prominent angles, and nine screws just as distinctly nine angles. It should be borne in mind that the mounting was an inch thick, and that it was turned to fit the surface of the bracket; that the screws were always set up by hand and never with a screwdriver, and hence were certainly loose; that, finally, the lenses were loose enough to rattle in their cells, and nevertheless the glasses were bent out of shape.

In regard to the position of the star points, it should be noted that the points were always in the angles between the lines drawn from the center to the screws. If, for example, the objective was secured with three screws, the star image was triangular, with the points lying in planes passing through the optical axis and bisecting the angles between the screw-heads. Finally, in order to conclude these experiments, I resolved on an infinite number of points; that is, I soldered a heavy mounting to the bracket, and afterwards cut in it the thread for the cells of the aplanatic. When this was done, behold! there were no more points on the stars.

The independent distortion previously discovered still remained, however, and it was now possible to undertake the correction of this also.

Since the lenses appeared to be quite free in their cells, the pressure causing the distortion was apparently due to the unequal distribution of the weight of the lenses on the points of support. It was easy to trace and correct the fault in this case, from a consideration of the manner in which the telescope lenses were mounted. The cells were so arranged that the lenses rested on three points of their periphery, and were held in position by an elastic ring, which pressed them against the points of support. The same construction is applied with equal facility to portrait lenses. In the case of those aplanatics in which a small meniscus is cemented into a larger one its application is more difficult. A thin metal ring must then be cemented to the periphery of the larger meniscus, extending slightly inward over the smaller one—a construction which is also occasionally adopted for other reasons. The elastic ring is then made to press against this ring of metal.

In most cases it is naturally sufficient to alter the arrangement of the cells as just described, since the influence of the screws in the flange of the mounting is removed at the same time. My course was that offered by the character of the investigation. Later I made only this second change. In this manner I have so improved all my objectives that they give the circular star images required.

It should not be supposed that these distortions of an image are only of importance in astronomical photography, where great accuracy is necessary. The photographs of ordinary terrestrial objects were materially improved after I had mounted a rather large lens in such a manner that it was as free from strain as possible. The known inferiority of definition of large objectives as compared with smaller ones has its origin largely in this defect, which must be much more pronounced in large objectives, and larger stops could be used with plates of the same size, if more care were taken in mounting lenses in their cells.

SOME RECENT ATTEMPTS TO PHOTOGRAPH THE FACULÆ AND PROMINENCES.*

J. EVERSHED, JR.

Nearly two years ago, when I first succeeded in obtaining photographs of the Solar Prominences in F light, using isochromatic plates, the idea occurred to me to try and obtain images not only of the prominences on the limb, but also those which must be projected on the disk of the Sun, and for this purpose I proposed to exclude from the sensitive film all parts of the spectrum excepting the dark line F, which would be made to coincide exactly with a narrow slit in a screen placed in front of the plate; and it was the reversals of this line, or rather the variations in intensity, that might occur while the Sun's image was allowed to transit the spectroscope slit, which were to record themselves on the sensitive plate, to which a corresponding motion would be given by clockwork or otherwise, in order that the successive images of the F line should fall on different parts of the plate and so build up, as it were, a continuous and complete image of the whole disk in absolutely monochromatic light.

I was rather deterred from carrying out this idea on considering that, after all, the chromosphere which envelops the whole surface of the Sun is itself brighter than most of the prominences, and consequently the intensity of the hydrogen lines would not probably be very different even where prominences overlaid the chromosphere. In other words, there would be no contrast sufficient to make the forms visible when projected on the brighter background, any more than in the case of Jupiter's satellites, which usually become invisible during transits, as soon as they have entered a short distance within the planet's limb.

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* *Journal, British Astronomical Association Vol. III. No. 6.*

Recently, however, Professor Hale's discovery that the two calcium lines H and K are not only brightly reversed in the prominences, but also in irregular patches on the disk corresponding to the faculæ, has induced me to make the necessary arrangements and alterations in the spectroscope so as to obtain monochromatic images as above described, only using H or K light instead of F; this being essentially Professor Hale's method of photographing the faculæ. I still think it may be worth while to take photographs in F light and compare these with the K images, but it is quite certain that the ordinary faculæ will not be shown as they do not reverse the hydrogen lines.

In a preliminary way I have obtained numerous photographs of the spectrum of portions of the solar disk including spot-regions, faculæ, and prominences; the results, so far, seem to agree in all respects with Professor Hale's recent work. Thus I have found that all hydrogen prominences reverse H and K brightly, and the forms in these lines are the same as in C. Also on the disk the calcium lines are frequently reversed, and sometimes doubly reversed over large areas, and there is no doubt that these reversals correspond with the faculæ, for when the latter show in the spectrum as bright bands parallel with the dust lines, H or K are always bright where the bands cross them.

The first successful photographs in K light, of the whole disk by the transit method, using the grating belonging to this Association, were obtained on February 19, this year, and these show an enormous mass of faculæ surrounding and following a large spot a little past the central meridian in the southern zone; the K reversals cover an area of, roughly, 500 square degrees of the Sun's surface in the neighborhood of the spot, and besides this there is shown a series of faculæ crossing the disk from the N. E. to near the W. point in the latitude of the northern spot zone. Photographs taken at later dates show in general the two series of faculæ crossing the disk in the two spot zones. The large group of February 19 was photographed again on March 12 and 19, after a rotation, and these negatives show that whilst the spot itself had become more conspicuous, the faculæ surrounding it were much fainter, and appeared to be breaking up into scattered fragments.

With regard to prominence photography, I have obtained fairly successful negatives by simply photographing a portion of the spectrum, including either the F hydrogen line, or, better still, H to K, and opening the slit as wide as circumstances will allow keeping the Sun's limb stationary a few seconds off the edge by clock movement. In this case I find that four or five prisms (of 60°) are much more suitable than a grating, as the loss of light is far less, and the exposure may be cut down to even a small fraction of a second, thus reducing atmospheric tremors and irregularities in the driving clock to a minimum. Using a semicircular slit in this way, it has been found possible to photograph 90 degrees or more of the limb showing chromosphere and prominences; but it requires great care to get the Sun's image exactly concentric. The plan I adopt is to take advantage of the undispersed white light reflected from the first surface of the first prism. A long focus lens (I use a spectacle lens of 2 feet focus) is placed near the first prism in the course of the reflected rays, which are thereby brought to a focus at a little distance from the instrument; a piece of white paper is placed sufficiently near the focus to show a sharp image of the slit, the R. A. and Dec. slow motions are then moved until the image of the Sun's limb is seen to just overlap the slit equally in all parts of the half circle. As the slit has to be adjusted in the focal plane of the refractor for the region of the spectrum near K, the white light image will be slightly out of focus, and must therefore be made to overlap the edge of the slit slightly, to ensure that the K image is exactly concentric.

I propose during this year to try and photograph the prominences by the transit arrangement designed for photographing the faculæ, but using four prisms instead of the grating, and limiting the field to a portion only of the limb; by this means I hope to get sharp and dense images of single prominences on a scale of 3 inches or more to the solar diameter.

To succeed in this it will be necessary to observe the K line visually, in order to bring it into exact coincidence with the slit. I do not anticipate much difficulty, however, in making this adjustment, as the prismatic spectrum is very bright, and K is easily seen when the eye is not fatigued. When a grating is used, one can make use of the overlapping spectra; thus, to bring the third order K on the slit, the second order D, which is very easily recognized, must be made to nearly coincide, the distance of the centre of the slit from D′ being made almost equal to that between D′ and D″.

This depends on the fact that three waves of K light very nearly equal in length two D waves, the yellow and violet light being superposed; whilst the latter only impresses the sensitive film.

The instruments I have used in making these experiments in solar photography consist of an equatorial retractor of 2½ inches aperture only; it is provided with a spectroscope in which either a grating or a prism train can be used. A small plane mirror, placed just to one side of the collimator lens, receives light at a very low angle from the grating, and reflects it into an observing telescope of ¾ inch aperture and seven inches focus, placed in a convenient position for visual work. Another similar telescope is attached on the other side, its O.G. being close alongside the collimator lens; this receives light direct from the grating at an angle of diffraction of about 15°. The photographic plate-holder is attached about four inches behind the eye-piece of this telescope where the monochromatic image of the Sun is formed; this is either about four or eight times larger than the image on the slit-plate, according to the eye-piece used. The plate-holder, when attached to the eye-piece is also firmly clamped to the body tube of the refractor, thus securing perfect rigidity, the whole spectroscope being previously fixed in position angle, so that the two slits are perpendicular to the Sun's motion. The plate is made to slide across the slit admitting the K light by means of a cord drawn by a weight, the requisite uniformity of motion being secured by attaching the sliding frame to a piston working in a cylinder of 1 inch bore filled with water; a small hole in the piston allows the water to slowly pass from one end of the cylinder to the other during the stroke, and a valve also in the piston allows the water to pass freely back again on the return stroke. The speed can be varied to suit the varying time of transit of the solar image by altering the weight; with a given weight the speed will be nearly constant, depending only on the rate of flow of the water through the small hole in the piston, which can hardly vary appreciably with ordinary changes of temperature. With the weight properly adjusted, monochromatic images may be obtained free from all distortion, excepting that due to the slight curvature of the K line, and this is practically inappreciable, and can be allowed for if necessary.

In conclusion, I should like to refer anyone who might wish to take up this branch of solar work to the very interesting article by Professor Hale on the spectroheliograph, in the March No. of ASTRONOMY AND ASTRO-PHYSICS. In this he not only describes his own methods, which are certainly by far the best yet devised for monochromatic solar photography, but he also gives an account of all other similar proposals and attempts made in recent years, giving in fact, a complete history of the subject beginning with Professor Young's first attempts to photograph prominences by means the of H_γ line and the wet collodion process, and concluding with his own latest devices, some results of which we have lately had the pleasure of seeing at a recent meeting of this association.

KENLEY, Surrey.

ON THE SUN'S ROTATION AS DETERMINED FROM THE POSITIONS OF FACULÆ.*

A. BELOPOLSKY.

Since the summer of 1891 I have obtained, by means of slow plates, a series of photographs of the Sun which show many details, and in which the faculæ are excellently defined.

I have selected a number of these plates and have studied especially those faculæ whose appearance changed very little during their time of visibility, so that they could be identified on different plates without doubt. This is confessedly a difficult task, since even in the interval of one day the form of a facula is likely to change beyond recognition. So that it is only exceptionally that a single point on a facula can be followed for more than two days. The positions of certainly identical faculæ were determined by a Troughton and Simms measuring engine, and the rectilinear co-ordinates were transformed into heliographic longitude and latitude by the tables of De la Rue and Spörer. I have attempted to use these determinations to obtain the daily rotation angle of the Sun. Of course, it is not possible by this means to fix a reliable numerical value for the angular velocity but it is possible to compare the angular velocity at the solar equator as determined by the Sunspots with the values obtained from my faculæ observations. According to Dr. Wilsing the angular velocity of the faculæ does not vary with heliocentric latitude.

In the following table I give the dates between which the faculæ positions are used; the limits of heliocentric longitude l; the heliocentric latitude b; the resultant angular velocity ζ_0; the sum of the intervals employed expressed in hours (column headed t); the angular velocity computed by Spörer's formula viz.:

$$\zeta_0 = 8.^\circ548 + 5.^\circ798 \cos b;$$

the difference $\zeta_c - \zeta_o$; and finally, the difference $14^\circ.27 - \zeta_o$; where $14^\circ.27$ is the angular velocity of the faculæ as determined by Dr. Wilsing.

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* Translated from *Mem. Soc. Spectroscopisti Italian*, Nov. 1892.

Pulkowa 1891.	*l*	*b*	ζ_o	*t*	ζ_c	$\zeta_c - \zeta_o$	14°.27 − ζ_o	
	° °	°	°	°	°	°	°	
July 20-22......	234.9–269.8	− 23	13.65	98.13	13.88	+ 0.23	+ 0.62	
Sept. 3-4	279.5–302.3	+ 28	13.39	81.80	13.67	+ 0.28	+ 0.88	I
Id "	285.0–307.4	+ 27	13.11	81.80	13.74	+ 0.63	+ 1.16	
Id "	287.8–311.8	+ 24	14.13	81.80	13.85	− 0.28	+ 0.14	
Id "	285.1–308.9	+ 22	13.97	81.80	13.92	− 0.05	+ 0.30	
Sept. 3 4	290.5–300.8	− 22	13.60	18.15	13.92	+ 0.32	+ 0.67	II
Id. "	288.8–313.3	− 25	14.35	81.80	13.80	− 0.55	− 0.08	
Id. "	292.3–302.6	− 24	13.70	18.15	13.85	+ 0.15	+ 0.57	
Id. "	298.8–310.7	− 23	(15.70)	18.15	13.89	− 1.81	− 1.43	
Sept. 10-12......	49.6– 67.5	+ 26	14.12	30.40	13.39	− 0.36	+ 0.15	
Id. "	288.0–305.8	+ 12	14.07	30.40	14.22	+ 0.15	+ 0.20	III
Id. "	296.4–314.0	+ 11	13.90	30.40	14.24	+ 0.34	+ 0.37	
Sept. 12-14......	39.2– 77.3	+ 33	13.91	150.25	13.39	− 0.52	+ 0.36	IV
Id. "	39.0– 76.3	+ 35	13.62	197.04	13.30	− 0.32	+ 0.65	
Sept. 13-14......	63.9– 75.6	+ 30	13.61	42.91	13.57	− 0.04	+ 0.66	V
Id. "	66.8– 80.3	+ 27	13.70	42.91	13.71	+ 0.01	+ 0.57	
Id. "	64.0– 77.7	+ 28	13.76	42.91	13.67	− 0.10	+ 0.51	
Sept. 13-14......	61.0– 75.3	+ 22	14.29	42.91	13.92	− 0.37	− 0.02	VI
Id. "	65.9– 80.1	+ 19	14.25	42.91	14.03	− 0.02	+ 0.22	
Id. "	67.9– 80.4	+ 18	13.49	42.91	14.06	+ 0.57	+ 0.78	
Id. "	70.1– 83.9	+ 19	13.55	42.91	14.03	+ 0.48	+ 0.72	
Id. "	68.2– 80.4	+ 21	12.01	42.91	13.96	+ 1.95	+ 2.26	
Sept. 29-30......	74.0– 86.2	− 25	13.22	22.10	13.84	+ 0.58	+ 1.05	VII
Id. 30-31......	64.6– 89.5	− 21	12.78	46.74	13.91	+ 1.18	+ 1.49	
Oct. 3-3	311.6–325.0	+ 20	13.75	23.35	14.00	+ 0.25	+ 0.52	
Id. 1-3	306.2–333.7	+ 25	13.26	96.55	13.80	+ 0.54	+ 1.01	VIII
Id. 3	315.6–329.5	+ 28	14.19	23.55	13.07	− 0.52	+ 0.08	
Oct. 3-4	86.2– 93.2	+ 31	13.89	93.54	13.52	− 0.37	+ 0.38	IX
Id. "	70.0– 97.0	+ 25	13.48	93.54	13.80	+ 0.32	+ 0.79	
Oct. 3-4	78.4– 92.7	+ 21	14.70	23.41	13.96	− 0.74	− 0.43	X
Id. "	79.0– 93.1	+ 18	14.55	23.41	14.06	− 0.49	− 0.28	
Oct. 6-7	84.0– 97.0	+ 28	13.19	23.94	13.67	+ 0.48	+ 1.07	XI
Id. "	86.5–100.2	+ 31	13.75	23.94	13.52	− 0.23	+ 0.52	
Id. "	88.1–101.9	+ 28	13.85	23.94	13.67	− 0.18	+ 0.42	
Oct. 6-7	316.5–330.1	+ 22	13.55	23.94	13.92	+ 0.37	+ 0.72	XII
Id. "	318.4–343.8	+ 23	13.58	89.74	13.88	+ 0.30	+ 0.69	
Id. "	318.8–344.5	+ 24	13.74	89.74	13.85	+ 0.11	+ 0.53	
Oct. 6 7	320.4–345.0	+ 26	13.17	89.74	13.76	+ 0.59	+ 1.10	XIII
Id. "	319.8–345.6	+ 28	13.78	89.74	13.67	− 0.11	+ 0.49	
Oct. 7	314.0–326.0	+ 26	13.53	20.92	13.76	+ 0.23	+ 0.74	XIV
Id. "	319.7–331.9	+ 24	14.00	20.92	13.85	− 0.15	+ 0.27	
Id. "	317.6–329.7	+ 25	13.95	20.92	13.80	− 0.15	+ 0.32	

From this table it will be seen that all the angular velocities determined by me (excepting 5 out of the 42), are smaller than those of Dr. Wilsing, as is also evident from the signs of the column headed 14°.27 — ζ_o. Most of the faculæ chosen lie in the zone 20° — 55°. It is evident, therefore, that the rotation of the faculæ is smaller than the rotation of the equator as determined by spots; and smaller also than the value obtained by Wilsing working on his hypothesis. The differences $\zeta_c - \zeta_o$ have different signs, and the numerical values of ζ_o are approximately those of the angular velocities of spots. The similarity is still more striking if we take the mean value of the several members of a group of faculæ. In this manner we can form from the table 14 groups as indicated by the brackets. One thus derives the following table, where the column ζ_o indicates the mean angular velocity of the faculæ, and ζ_c, the same for the spots of corresponding latitude. In the first line of the table is placed a single isolated facula, which is entitled to greater weight than the others. The sums of positive and negative differences are almost the same.

	ζ_o	ζ_c	$\zeta_c - \zeta_o$		ξ_o	ξ_c	$\zeta_c - \zeta_o$
	°	°	°		°	°	°
	13 65	13.88	+ 0.23	VIII............	13.73	13.74	+ 0.01
I	13.65	13.79	+ 0.14	IX............	13.69	13.66	− 0.03
II	14.34	13.86	− 0.48	X............	14.63	14.01	− 0.62
III	13.99	14.23	+ 0.24	XI............	13.60	13.62	+ 0.02
IV	13 77	13.35	− 0.42	XII............	13.62	13.88	+ 0.26
V	13.69	13.65	− 0.04	XIII............	13 48	13.72	+ 0.24
VI	13.72	14.00	+ 0.28	XIV............	13.83	13.80	− 0.03
VII	13.00	13.88	+ 0.88				

It may be objected to my determinations that the positions of the faculæ, which of course all lie very near the limb of the Sun, can be affected somewhat by refraction in the solar atmosphere. But in the first place, we have to deal only with differential positions, so that we may expect to find the greater part of the refraction eliminated. In the second place, the influence of refraction, if indeed any still remain, is such that the angular velocity obtained will be greater than the true value. I may add, what has long been known, that groups of spots are always surrounded by faculæ, and that both phenomena are intimately connected. It would, therefore, be a very remarkable thing if the rotation period of the faculæ differed in general from that of the spots, or from the overlying layer of the Sun whose rotation Professor Dunér has found to be almost identical with that of the spots. I believe that the law of spot-rotation is applicable not merely to a thin stratum of the Sun, but to the rotation of the body as a whole.

PULKOVA, November 1892.

ON THE DETERMINATION OF THE SUN'S ROTATION FROM THE POSITIONS OF FACULÆ.*

DR. WILSING.

In the November number of the *Memorie della Societa degli Spettroscopisti Italiani*, Mr. Belopolsky published some measures of the positions of faculæ obtained from photographic plates. The discussion of these measures leads him to the conclusion that the law of rotation of faculæ is identical with that of spot rotation, a result which differs from that obtained by me, namely, that that stratum of the Sun which gives rise to the faculæ rotates with an angular velocity which is constant and therefore independent of the heliocentric latitude. His conclusion, however, appears to me from the following considerations to be scarcely warranted. In Mr. Belopolsky's series of measures, the greatest difference of time between two observations of the same object never exceeds two days. Now, in consequence of this small interval, the value of the rotation angle must be strongly influenced by errors both constant and variable. It would appear, therefore, somewhat hazardous to draw such conclusions from observations of 42 faculæ lying in the zone ± 11° to ± 35°. Mr. Belopolsky is satisfied, however, with a comparison of his values with those computed from Spörer's formula for the angular velocity of spots, viz.:

$$\xi = 8^\circ.548 + 5^\circ.798 \cos b:$$

for he finds the sum of the differences between his observed values and those thus computed is practically zero, while the deviations between his observations and the constant angle of rotation found by me all lie in one direction.

I may here remark that the mere fact of the positive and negative differences adding up to zero is in itself no proof that the formula employed represents the physical fact; for there is an infinite number of formulæ which will satisfy this condition. We must add one other condition to be satisfied by the observation, viz., the deviations must not be systematic with reference to the

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[*] Translated from *Astronomische Nachrichten*, No. 3153.

data; in other words there must be no "error of run;" the deviation must not depend upon the value of the argument. To test this in the present case, we may arrange the observations according to their heliocentric latitude. This I have done, preserving in the faculæ of the same latitude the chronological order of Mr. Belopolsky's table. The first column contains the heliocentric latitude, b; the second, the observed rotation angle, ξ_o; the third the difference $\xi_c - \xi_o$ where ξ_c is computed from the formula $\xi_c = 8^\circ.548 + 5^\circ.798 \cos b$; the fourth column, the difference $14^\circ.27 - \xi_o$.

b	ξ_o	$\xi_c - \xi_o$	$14^\circ.27 - \xi_o$	b	ξ_o	$\xi_c - \xi_o$	$14^\circ.27 - \xi_o$
	°	°	°		°	°	°
+ 11	13.90	+ 0.34	+ 0.37	− 25	14.35	− 0.55	− 0.08
+ 12	14.07	+ 0.15	+ 0.20	− 25	13.22	+ 0.58	+ 1.05
+ 18	13.49	+ 0.57	+ 0.78	+ 25	13.26	+ 0.54	+ 1.01
+ 18	14.55	− 0.49	− 0.28	+ 25	13.48	+ 0.32	+ 0.79
+ 19	14.25	+ 0.22	− 0.02	+ 25	13.95	− 0.15	+ 0.32
+ 19	13.55	+ 0.48	+ 0.72	+ 26	14.12	− 0.36	+ 0.15
+ 20	13.75	+ 0.25	+ 0.52	+ 26	13.17	+ 0.59	+ 1.10
+ 21	32.01	+ 1.95	+ 2.26	+ 26	13.53	+ 0.23	+ 0.74
− 21	12.78	+ 1.18	+ 1.49	+ 27	13.11	+ 0.63	+ 1.16
+ 21	14.70	− 0.74	− 0.43	+ 27	13.70	+ 0.01	+ 0.57
+ 22	13.97	− 0.05	+ 0.30	+ 28	13.39	+ 0.28	+ 0.88
− 22	13.60	+ 0.32	+ 0.67	+ 28	13.76	− 0.09	+ 0.52
+ 22	14.29	− 0.37	− 0.02	+ 28	14.19	− 0.52	+ 0.08
+ 22	13.55	+ 0.37	+ 0.72	+ 28	13.19	+ 0.48	+ 1.08
− 23	13.65	+ 0.23	+ 0.62	+ 28	13.85	− 0.18	+ 0.42
− 23	(15.70)	(− 1.81)	(− 1.43)	+ 28	13.78	− 0.11	+ 0.49
+ 23	13.58	+ 0.30	+ 0.69	+ 30	13.61	− 0.04	+ 0.66
+ 24	14.13	− 0.28	+ 0.14	+ 31	13.89	− 0.37	+ 0.38
− 24	13.70	+ 0.15	+ 0.57	+ 31	13.75	− 0.23	+ 0.52
+ 24	13.74	+ 0.11	+ 0.53	+ 33	13.91	− 0.52	+ 0.36
+ 24	14.00	− 0.15	+ 0.27	+ 35	13.62	− 0.32	+ 0.65

Let us now bunch these 42 differences in 5 groups of 8 or 9 observations each. The following table will then contain in successive columns the mean heliocentric latitude of the group; the mean of the difference $\xi_c - \xi_o$ for each group. The differences of these from the mean of all the observations; the mean of the difference $14^\circ.27 - \xi_o$ for each group; and finally, the deviations of these from the mean of all the observations. The figures enclosed in brackets in the second row are from the last values of the second group, which Mr. Belopolsky indicates as doubtful.

Mean hel. lat.	$\xi_c - \xi_o$	$(\xi_c - \xi_o) - 0^\circ.11$	$14^\circ.27 - \xi_o$	$(14^\circ.27 - \xi_o) - 0^\circ.56$
17	+ 0.38	+ 0.27	+ 0.57	+ 0.01
22	+ 0.13 (− 0.11)	+ 0.02	+ 0.48 (+ 0.24)	− 0.08
24	+ 0.11	0.00	+ 0.55	− 0.01
27	+ 0.07	− 0.04	+ 0.61	+ 0.05
31	− 0.16	+ 0.27	+ 0.52	+ 0.01
	+ 0.11		+ 0.56	

Now the deviations of the means for the different zones given in the third column indicate a distinct systematic error whose size and sign depend upon the numerical constants of the formula, showing that the observations are not represented by the formula. A glance at the fifth column, on the other hand, shows that on diminishing the value 14°.27 by the constant 0°.56, the observations in the zone between 11° and 35° latitude are perfectly represented. If one cares to draw any conclusion from these observations, it can only be that between Mr. Belopolsky's results and my own there is a constant difference, that his observations are perfectly represented by a constant rotation angle, and that they do not obey the rotation-law derived from the observation of spots.

Finally, I may call attention to a certain misconception of my work which appears to underlie the remarks of Mr. Belopolsky. The purpose of my investigation was to learn whether the faculæ have a rotation angle whose value is constant in this sense, viz., that the coincidences between computed and observed positions, extending over a long interval of time, are not merely accidental. The existence of such a value demands, in the first place, that the conditions in the interior of the Sun, necessary for the formation of the faculæ, should remain more or less constant for a long time. It is not, however, necessary that the faculæ themselves, which alone are available for observation, and which are a surface phenomenon, should during any short interval be independent of the general drift of the surface. For the purpose of illustration let me take an example from the physics of the Earth. The average absolute motion of the eruptive matter from any volcano is determined by the prevailing air currents of that locality, and is therefore, different in different parts of the Earth's surface, while the angular velocity of the center of eruption remains the same. If, however, one could observe at long intervals the eruptions of the same volcano he would, by a combination of these, obtain the true and constant rotation period of the Earth, from which would be eliminated all influence of atmospheric motion.

ON THE ROTATION OF THE SUN AS MEASURED BY THE POSITION OF FACULAE.*

A. BELOPOLSKY.

Greater attention has been paid my article on the rotation of the Sun from the positions of faculæ† than I expected, for I had

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* *Astronomische Nachrichten*, No. 3158. † *Memorie degli spett. Ital.*, vol. XXI.

merely designed to point out that the study of the position of faculæ is of the highest importance, and that the comprehensive work of Wilsing had not yet settled the question.

Since the publication of the article, I have received letters from two distinguished investigators of the Sun-spots, Spörer and Riccò, and, in No. 3153 of the *Astronomische Nachrichten*, another paper from Wilsing appears with a criticism of my results.

The first two observers wholly agree with my conclusions as to the meaning of the signs of the differences between the angular velocities of faculæ as observed at Pulkowa and at Potsdam. Professor Spörer, in addition, sends me a series of values of the angular velocity from the determinations at Potsdam, which stand in entire accord with mine.

The paper of Wilsing's, however, is directed against my conclusions and I beg leave therefore to give it a little closer attention.

In the first place I must repeat what I have already said in my communication, that the merely numerical values of the angular velocities which I obtained are too small to lay great stress upon. At the most one can take into consideration only the sign of the differences between these and other angular velocities. Wilsing, on the contrary, regards them as reliable, and draws conclusions therefrom which in my opinion do not perhaps harmonize entirely with his own views.

He overlooks, moreover, the fact that in my article I give a column (the fifth) in which the numbers can be regarded as the values of the angular velocities, and yet in this case the values play no unimportant part. A consideration of this column shows that the faculæ which I have examined lie, not in the great zone 11° — 35°, but only in the zone 23°. — 35° heliographic latitude. To find a law which is satisfied by the angular velocities within a zone of 12°, is surely not easily done even by the positions of spots. As an example, I give a series of angular velocities as obtained from the spots. It is to be remembered that a setting can be made with far greater accuracy on a spot than on a facula. Moreover the observations on the spots are separated from one another at least four days, and from that up to thirty-two days, while my observations of the faculæ are only about two days apart. And yet in the following table, the law of the decrease in rotation with the latitude is seen only with difficulty.

1875 (*Sporer*, *Publicationen zu Potsdam*, *vol. II*).

t	Latitude	ξ	t	Latitude	ξ
32*d*	18°	14°.22	8*d*	9°	14°.19
5	16	14 .04	8	8	14 .25
9	15	14 .28	10	7	14 .22
7	13	14 .04	10	7	14 .18
5	11	14 .17	9	6	14 .19
9	10	13 .94	4	4	14 .19
6	9	14 .61			

Whence we obtain as mean values:

Latitude	ξ
16°	14°.18
10	14 .19
7	14 .22
5	14 .19

All the less, then, can faculæ throw any light upon the law.

My tabulation of the angular velocities of faculæ and spots which appeared at the end of my communication was merely to show that upon the whole there was no contradiction between them.

The conclusion which is drawn from Wilsing's article and with which I also agree, points to an obvious and, as regards sign, a constant, difference between his determinations and those of mine, such that

$$W - B = + 0^\circ.56.$$

The groups of faculæ which Wilsing employed in his investigations in 1884 lay in the zone between 6° and 15°, or, at the utmost, between 6° and 18° as can be seen from an inspection of the values which he gave. My faculæ, as already noted, lie chiefly in the zone between 23° and 35°. One can easily see, therefore, that the former must rotate faster than the latter. (The spots in the zone 6°-18° rotate daily about 0°.6 faster than those in the zone 23°-35°.)

When we remember what a host of spot-observations forms the basis of the law of rotation already known, we must expect to have a still greater number of faculæ positions for the foundation of a law of rotation for the latter.

It would be very desirable to prepare further determinations of positions of faculæ with reference to the rotation of the Sun, in order to settle this important question; each facula, however, would have to be followed up without any definite hypothesis for the identification of the groups which had been observed after a long interval.

PULKOWA, February, 1893.

ASRTO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Congress of Mathematics, Astronomy and Astro-Physics.—In the extensive series of international Congresses now being held in connection with the Columbian Exposition, the Congress of Mathematics, Astronomy and Astro-Physics will occupy a prominent place. Its sessions will begin on Monday, August 21, 1893, in the Memorial Art Institute, Michigan Avenue, foot of Adams St., Chicago.

While it is still too early to announce the definite program of the Congress, we are able to append a partial list of the papers to be read in the Section of Astro-Physics:

Professor H. A. Rowland, Johns Hopkins University. "The Solar Spectrum."

Professor S. P. Langley, Smithsonian Institution. On Bolometric Investigations.

Professor E. C. Pickering, Harvard College Observatory. "The Constitution of the Stars."

Professors Kayser and Runge, Technische Hochschule, Hannover, Germany. "The Spectra of the Elements."

M. H. Faye, Paris. "Theory of the Sun."

Professor F. H. Bigelow, U. S. Weather Bureau. "Magnetic Fields of the Sun."

Mr. E. Walter Maunder, Royal Observatory, Greenwich. "The Classification of Stellar Spectra."

Dr. H. Ebert, Erlangen, Germany. "Electro-Magnetic Theory of the Corona."

Rev. Walter Sidgreaves, S. J., Stonyhurst Observatory, Lancashire, England. "The Stonyhurst Solar Investigations."

Rev. F. Denza, Observatory of the Vatican, Rome. "Astro-Photographic Investigations."

Professor W. W. Campbell, Lick Observatory. "The Wolf-Rayet Stars."

Professor Fitzgerald, Dublin. "Terrestrial Magnetism."

Dr. A. Brester, Jz., Delft, Holland. "Theory of the Sun."

Herr Victor Schumann, Leipzig, Germany. "Photographic Investigations in the extreme Ultra-Violet."

Messrs. L. E. Jewell and Joseph S. Ames, Johns Hopkins University. (1). "Constitution of the Oxygen Absorption Bands." (2). "Variation in Metallic Lines with amount of Metal in the Arc." (3). "An Absolute Photometric Scale for Spectrum Lines."

The above list, while incomplete, will serve to indicate the nature of the program. For the Sections of Mathematics and Astronomy, a large number of papers have been promised. Among foreign astro-physicists already in this country or expected in time for the Congress may be mentioned Professor P. Tacchini, Dr. Max Wolf, Herr Eugen von Gothard, Professor James Dewar, Mr. A. Cowper Ranyard, Professor W. N. Hartley and Dr. H. Ebert. The discussions following the reading of papers will be stenographically recorded, and published in the volume of proceedings.

A cordial invitation to attend the sessions of the Congress is extended to everyone interested. Further information may be obtained by addressing George E. Hale, Secretary of the Local Committee, Kenwood Observatory, Chicago.

Astronomical Exhibits at the Columbian Exposition.*

Exhibit of the U. S. Naval Observatory, (east of the United States Government Building) in charge of Lieut. A. G. Winterhalter, U. S. N.

Small Observatory with 5-inch equatorial refractor.
40-foot photoheliograph.
3-inch transit, clocks, large collection of chronometers.
Publications of the U. S. Naval Observatory.
Photographs, drawings, etc.

Manufactures and Liberal Arts Building, North Gallery.

WARNER & SWASEY.

40-inch Yerkes telescope.
12-inch equatorial telescope.
6-inch equatorial telescope.
4½-inch equatorial telescope.
4 inch telescope on tripod.

Chronograph, photographs of the Lick telescope, drawings of Washington 26-inch equatorial, dome and elevating floor. Photographs of Moon taken with the Lick telescope.

J. A. BRASHEAR.

Stellar spectroscope for the 40-inch Yerkes telescope.
2 standard spectroscopes.
6½-inch equatorial reflector.
Small equatorial mounting and heliostat.
18-inch objective and smaller objectives.
Plane and parabolic specula, gratings, micrometers, helioscopes, prisms, etc.
Photographs of Lick and Princeton spectroscopes.

GEORGE N. SAEGMULLER.

9-inch equatorial telescope, Clacey objective with photographic corrector.
4-inch equatorial telescope.
4-inch steel meridian circle.
2-inch transit.
3-inch transit.
2 chronographs, astronomical clocks.
Photographs of transits and other instruments.

PROFESSOR GEORGE W. HOUGH.

Printing chronograph.

BRITISH ASTRONOMICAL ASSOCIATION.

Exhibit of publications, drawings, etc.

KENWOOD OBSERVATORY.

Photographs of Observatory, instruments, solar prominences, faculæ and ultra-violet spectrum of chromosphere.

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* The following list of exhibits is not complete, but even in its present form it may be of some service to visitors at the Exposition.

Professor James E. Keeler.

Drawings of Jupiter and Saturn.

Observatory of the Vatican.

Set of publications.

Professor P. Tacchini.

21 volumes Memorie della Societá degli Spettroscopisti Italiani.
23 volumes Annali dell 'Ufficio Meteorologio E Geodinamico Italiano.
13 volumes Rivista Meteorico Agraria.
26 volumes Bollettino Meteorico Geornalier.

East Gallery.

Vion Frères (Paris).

Small refractors and reflectors.

Pellin (Paris).

Darsonval spectro-photometer.
Large Silbermann heliostat.

Teigne et Moreau (Paris).

Small equatorial telescope.

Werlein (Paris).

Glass, quartz, fluorspar, etc.

Professor Lippmann (Paris).

Photographs of spectra and other objects in colors.

West Gallery.

German Educational Exhibit.

Kirchhoff's original spectroscope.

Jena optical glass, spectro-photometer, mercury pumps, (Gerhardt, Bonn).

Set of mathematical models, (Brill). Guericke's original air-pump.

Computing machines, Geissler pumps, scientific books,

Original magnetic apparatus of Gauss and Weber, Diamagnetometer, Photographs of magnetic instruments (from the Gauss Erd-Magnetisches Observatorium, Goettingen, Germany).

Photographs of the photographic equatorial, stellar spectrograph and magnetic instruments; copies of magnetic curves, Astrophysikalische Observatorium, Potsdam.

Royal Astronomical Society.

14 photographs of stars, nebulæ, etc., by Dr. Isaac Roberts.

2 large photographs of composite drawing made from all the negatives of the total solar eclipse of 1882. Photographs of the eclipses of 1870, 1871, 1882, 1883 and 1886. Photographs of the compared spectra of the Sun and meteorites from D to K, by Sergeant Kearney, R. E. Series of nine photographs of the Great Sunspot of February 1892. Spectra of the Sun, Arcturus and Nova Aurigæ. Thirteen photographs of stellar spectra.

Photographs from the Royal Observatory, Greenwich, including chart plates of the Pleiades, catalogue plate with trail for orientation, ω^2 Cygni (seven exposures), photographs of the Sun, etc.

Photograph of the Great Comet of 1882, by Dr. David Gill.

Capt. Abney's photograph of the Infra-red solar spectrum.

DR. A. A. COMMON.

Parabolic speculum of 5-feet aperture (unsilvered).

THE EARL OF ROSSE.

4 drawings of the Milky Way, by Dr. Otto Boeddicker.

West Gallery, Third Floor.

SCHMIDT UND HAENSCH.

Large spectro-photometer.

FUESS.

Heliostat.

South Gallery.

HARVARD COLLEGE OBSERVATORY.

Several hundred photographs of instruments and observatories in Cambridge, Colorado, California, Chili and Peru, stellar spectra, double stars, star trails, comets, clusters, nebulæ, the solar corona, Moon, Jupiter and satellites, Mars, Saturn and satellites, Uranus and three satellites, Neptune and satellite, etc., etc.

AMHERST COLLEGE.

Pneumatic commutator sheet used in operating automatic eclipse instruments. Photographs of automatic eclipse instrument, 40-foot telescope, and other instruments used at the African eclipse of 1889. Photographs of the transit of Venus photoheliograph, and enlarged photograph of Sun with Venus in transit. Photographs of the Amherst Observatory, equatorial and transit instrument.

UNIVERSITY OF THE CITY OF NEW YORK.

Photographs of stellar spectra, etc., by Dr. Henry Draper.

Bronze bust of Dr. Henry Draper.

Print from photograph of 40-foot telescope at Slough, taken by Sir John Herschel in 1839. Original daguerreotype of solar spectrum, taken by John W. Draper in 1842. Oldest existing daguerreotype, taken by John W. Draper in 1840.

JOHNS HOPKINS UNIVERSITY.

Rowland and Rutherfurd gratings. Photographs of solar and metallic spectra by Professor Rowland.

PRINCETON UNIVERSITY.

Photographs of the Halsted Observatory and Students' Observatory.

The Rittenhow Orrery (1770).

CARLETON COLLEGE.

Drawings of Venus, Jupiter and Holmes' Comet, by Dr. H. C. Wilson.

Photographs of the Observatory, Sun, Moon and Orion Nebula.

DE PAUW UNIVERSITY.

Dr. Chandler's original 4-inch almucantar.

Photographs of the Observatory, equatorial, meridian circle, and chronograph.

BELOIT COLLEGE.

Photographs of the Observatory and equatorial.

YALE UNIVERSITY.

Photographs of the Observatory and heliometer.

LEHIGH UNIVERSITY.

Photographs of the Observatory, equatorial and zenith telescope.

UNIVERSITY OF WISCONSIN.

Photographs of Observatory, equatorial, and dome and equatorial of Students' Observatory.

UNIVERSITY OF MICHIGAN.

Photographs of Observatory, equatorial, meridian circle and Practice Observatory.

MOUNT HOLYOKE COLLEGE.

Photographs of Observatory, equatorial and transit instrument.

SMITH COLLEGE.

Photographs of Observatory and equatorial.

VASSAR COLLEGE.

Photograph of Observatory.

CLARK UNIVERSITY.

Photographs of Michelson's interferential refractometer, mathematical models and physical instruments.

WESTERN UNIVERSITY OF PENNSYLVANIA.

Langley's original bolometer, photographs of infra-red solar spectrum, equatorial telescope, stellar spectroscope, transit instrument, galvanometer and switchboard. Mathematical models by Professor R. T. Stewart.

Main Isle (Swiss Exhibit).

LA SOCIÉTÉ GENEVOISE.

Spectroscopes, spectrometers, heliostats, dividing engines, transits, etc.

Electricity Building, East Gallery.

MERZ (MUNICH).

9 objectives, 10-inch aperture and smaller.
2 equatorial telescopes.

VOIGTLÄNDER UND SOHN.

Photographic objectives.

SCHMIDT UND HAENSCH.

Universal spectroscope, spectro-photometer, polarizing apparatus, prisms, etc.

STEINHEIL (MUNICH).

Large spectrograph, spectroscope, spectrometer, small refracting telescope, prisms and telescope objectives.

DR. STEEG AND REUTER (BAD HOMBURG).

Glass, quartz and rock salt prisms, etc.

KRUSS (HAMBURG).

Large automatic 6-prism spectroscope,
Small automatic 6-prism spectroscope,
Universal spectroscope for qualitative and quantitative analysis.

BERNHARD HALLE (STEGLITZ).

Iceland spar polarizing prisms, prisms and plates of rock salt, alum, tourmaline, etc.

ZEISS (JENA).

Abbe spectrometer, with illuminating and heating apparatus, comparator for measuring spectra, photographic objectives, etc.

SCHOTT UND GENÖSSEN (JENA).

Large collection of optical glass, including a pair of 23-inch telescope discs.

MAX KOHL (CHEMNITZ, SAXONY).

Large induction coil and other physical apparatus.

S. REIFLER (MUNICH).

Astronomical clocks.

Agricultural Building—N. E. Corner.

CAPE COLONY EXHIBIT.

Dr. David Gill's photographs of stars, nebulæ, etc.

California State Building.

LICK OBSERVATORY.

Glass transparencies from photographs of the Milky Way, Moon, planets, comets, Observatory, instruments, etc.

The Total Eclipse of April 16.—In the *Comptes rendus* for May 15, M. Deslandres gives the results of his observations of the total eclipse in Africa. Twenty-two photographs of the corona were obtained with different objectives, plates and exposures. Some of the negatives show streamers equal in length to twice the solar diameter. The general form of the corona is that characteristic of maximum spot periods. In attempting to photograph the ultra-violet portion of the coronal spectrum and to determine the velocity of rotation of the corona by displacement of the lines a spectroscope of large dispersion was used without success. An instrument of smaller dispersive power allowed the spectrum to be photographed to the limit of the ordinary solar spectrum, and fifteen bright lines were obtained. In the determination of the rotation of the corona the spectra of opposite points of the corona, situated in the equatorial plane, and at a distance of two-thirds the solar diameter from the limb, were photographed edge to edge. The spectra showed a slight displacement, corresponding to a difference of velocity of from 5 km to 7.5 km. M. Deslandres concludes that the corona closely follows the photosphere in its motion. No dark lines were found in the coronal spectrum. The light of the corona was composed simply of bright lines and a strong continuous spectrum.

Report of the O-Gyalla Observatory for 1892.—We have received from Dr. Nicolaus von Konkoly the "Berichte aus dem astrophysikalischen Observatorium in O-Gyalla (1892)," a reprint from the "Berichte" of the Hungarian Academy. The number of Sun-spots in 1892 was determined from drawings made on 157 days, and a "relative number" (Wolf) of 53.63 resulted. Observations of meteors and meteor radiants were made in July and August at O-Gyalla, Pressburg and Budapest, and on certain occasions simultaneous observations were made at two stations. In all 264 meteors were recorded. The spectroscopic observations included those of Nova Aurigæ, Comet Swift, Comet Holmes and β Orionis. The spectrum of Comet Holmes, as observed on November 18, was so feeble that the colors of the faint continuous spectrum could be seen only with a very wide slit. During the year a large collection of meteorological instruments was added to the equipment of the Observatory.

Photography of the Spectrum of Comet Swift.—In Eder's "Jahrbuch," 1893, Herr Eugen von Gothard describes his photograph of the spectrum of Swift's

Comet, made in three days (in April, 1892) with a total exposure of four hours. For purposes of comparison the Bunsen burner spectrum was photographed on the same plate. The spectra were found to be identical as far as the fourth band (λ 473 — λ 467), but from there onward, appear new unknown lines and bands, (which are wanting in the comparison spectrum) with faint carburetted hydrogen bands (λ 389 — λ 387). These latter are not identical with, but quite similar to those which appear so characteristically in the carburetted hydrogen spectrum. It would thus seem that the compound of carburetted hydrogen existing in comets differs in composition from our coal gas, and probably exists under physical conditions different from those occurring in the Bunsen flame.

Spectroscopic Determination of Stellar Rotation.

To the Editor of Astro-Physics:

DEAR SIR: The widening of the lines in the spectrum of a star is generally ascribed to high temperature; and, no doubt, most of it is due to this cause; but must not a certain part be due to axial rotation? To make my meaning clear, suppose a distant star, situated in the plane of our Sun's equator, and suppose there to be an observer in this star, examining the light of our Sun with a good spectroscope; then one edge of the disc would be advancing towards him with a velocity of a little over one mile per second, while the other edge would be retreating with the same velocity. Other portions of the disc would be moving with intermediate velocities; so that the total effect would be to broaden out a fine line into a band, whose width would correspond to the algebraic difference of these velocities, viz., two miles a second. A similar effect ought to be visible to us, when examining the spectrum of a star, except in the improbable case of our being situated nearly in the prolongation of the stellar axis. In general, this effect would be mixed up with the widening produced by high temperature, so that it would be impossible, or nearly so, to separate the two. It seems to me, however, that even in this case something might be done with a telescope of large aperture and a spectroscope of considerable dispersive power, by the aid of the considerations that the broadening due to rotation ought to affect all lines equally, and that the distribution of intensities in different parts of the band ought to follow a uniform and easily deducible law. But in the case of variable stars, like Algol, where the diminution of light is supposed to be due to the interposition of a dark companion, it seems to me that there ought to be a spectroscopic difference between the light at the commencement of the minimum phase, and that of the end, inasmuch as different portions of the edge would be obscured. In fact, during the progress of the partial eclipse, there should be a shift in position of the lines; and although this shift is probably very small, it ought to be detected by a powerful instrument. J. R. HOLT.

A new Method of Stellar Photometry by Lagrange and Stroobant —The idea is to place a small incandescent electric lamp, near the objective, but outside the tube, of an ordinary refractor. Near the eyepiece, but in the side of the tube, is placed a short-focus lens. By means of two plane metallic mirrors, one in front of this lens and one behind it, an image of the small lamp is thrown into the field of the refractor.

To compare the brightness of the lamp with that of the star the following arrangement is used. An iris diaphragm is placed in front of the lamp, *i. e.*, on the side next the observer. In addition to this a pair of sliding colored glass wedges is arranged between the lamp and the iris diaphragm. It still remains to regulate the current in the lamp or to correct for its variations. The authors choose the latter alternative and keep a photographic record of the voltage of the lamp, from which, knowing the intensity of the light as a function of the voltage, they correct for any change in their standard.

A lamp of this kind is so very sensitive to any change in the E.M.F. of the battery that the method can hardly be said to inspire confidence.—[*Bull. Acad. roy. Belgique*, 3rd ser., *t.* 23, pp. 811-827. Reprinted in *Jour. de Physique* for April, 1893.]

Radiation of Rarified Gases, by K. Angström. This is a piece of work whose description covers thirty-eight pages in the current number of *Wiedemann's Annalen.* In it many large questions are started regarding the nature of the phenomena observed in a Geissler tube. The paper being confessedly preliminary and incomplete, one is not surprised on laying it down to find many of these questions almost untouched. The author measured, with a not very sensitive bolometer, the total radiation of a Geissler tube. To excite the tube he used either a tremendous storage battery of 800 cells interrupted by a tuning fork or the secondary of an induction coil. Currents were measured in amperes, not merely scale divisions, and the radiation reduced to gram-calories.

Four gases were examined, viz., oxygen, hydrogen, nitrogen and carbon-monoxide. Special attention was given to obtain the gases in a pure state. The oxygen and hydrogen were prepared electrolytically. Most of the measures were made on tubes in which the pressures ranged from 0.12 to 2.66 millimeters of mercury.

Under these circumstances, it was found, among other things, that—

1. For any single gas, under constant pressure, the radiation is proportional to the exciting current.

2. In any single gas, under constant pressure, the *ratio* of luminous to non-luminous radiation does not vary with the current.

[Here "non-luminous" rays are defined as those which do not pass through an alum solution. "Luminous" rays are those which do.]

3. The ratio between the energy which the tube *radiates* and that which the current developes in the tube (Joule effect) increases as the pressure of the gas decreases.

4. The optical efficiency of this radiant energy, *i. e.*, the proportion of it which is luminous, depends upon the nature of the gas. In the case of nitrogen, under low pressure, as much as 90 per cent of this radiation passes through the alum solution.

5. The total radiation from any tube is to be looked upon as a function, *primarily*, of the chemical constitution of the gas; and, *secondarily* only, as a function of the electric discharge. Molecular structure of the gas is the all-important factor.—[*Wied. Ann.*, Bd. 48, pp. 493-530 (1893).]

Flame Spectra at High Temperatures.—*Part 1. Oxyhydrogen Blowpipe Spectra.*—Brewster, in 1842, first examined the spectra of salts with a flame of oxygen and coal-gas (Proc. Roy. Soc., Edin., vi., p. 145.)

Professor Norman Lockyer has given us maps of twenty-two metallic spectra at the temperature of the oxygen and coal-gas flame. The region observed lies between λ 7000 and 4000.

Preparatory to undertaking the study of spectroscopic phenomena connected with the Bessemer "blow" and the manufacture of steel generally, I have carefully observed the spectra of metals and metallic oxides obtained by submitting the substances to the oxyhydrogen flame.

Method of Investigation.—The method of obtaining spectra with flames at high temperatures is the following. Hydrogen proceeding from a large lead generator is burnt in a blowpipe with compressed oxygen. The blowpipe measures 3 in. in length by ⅜ in. external diameter. The substances examined are supported in the flame on small plates of kyanite about 2 in. in length, one-twentieth in. in thickness, and ¼ in. in width. This mineral, which is found in masses in Co. Donegal, contains 96 per cent of aluminium silicate, and is practically infusible. The spectra were all photographed by me with the instrument employed by me on former occasions for photographing ultra-violet spectra, illustrations of which were published in the Chem. Soc. Journ., XLI., p. 91, 1882. The dispersion of the instrument was that of one quartz prism of 60°.

Isochromatic plates developed with hydroquinone were largely used. Various dyes for sensitising and all kinds of developing substances were tried. The spectra were measured with an ivory scale divided into hundredths of an inch, and directly applied to the photographs, the division 20 on the scale being made to coincide with the yellow sodium line which appears on every photograph. It was found convenient to record the measurements on a gelatine-bromide paper print taken from an enlarged negative. Sometimes, for more careful and minute reference, it was found convenient to make an enlargement of the spectrum with the scale in position, but accurate measurements cannot be made in this way. It is necessary to use a low magnifying power and cross-wires in the eye-piece.

For the identification of the lines already known nothing more complicated is required, but to measure new lines and bands it was considered desirable to make use of a micrometer and microscope; the screw of the micrometer was cut with 100 threads to the inch, and the magnifying power generally used was 10 diameters.

Characters and Extent of the Spectra Observed.—Just as in the ordinary use of the spectroscope we must be prepared to see the lines of sodium, and in hydrocarbon flames the bands of carbon, so in these spectra the sodium lines and the strongest lines belonging to the emission spectrum of water vapor are also always present.

In addition, the kyanite yields the red line of lithium, which is no inconvenience, but a positive advantage, serving, as it does, to indicate where the spectra commence.

A large majority of the metals and their compounds all terminate somewhere about the strongest series of water vapor lines. Typical non-metallic spectra are sulphur, selenium, and tellurium; the first yields a continuous spectrum with a series of beautiful fluted bands, the second a series of fine bands occurring at closer intervals, and the third is characterised by bands still closer together, and nearer the more refrangible termination of which four lines occurring in Hartley and Adeney's spark spectrum of tellurium are visible. Increase in atomic mass causes shorter periods of recurrence of bands. In line spectra it is the reverse; increase in atomic mass causes greater periods in the recurrence of lines. Charcoal and carbon monoxide yield chiefly continuous spectra; the latter, however, exhibits only carbon lines. The hydrocarbons yield the well-known spectrum of carbon bands with also those attributed to cyanogen. Of metallic elements, nickel, chromium and cobalt yield purely line spectra; antimony, bismuth, silver, tin, lead, and gold beautiful banded spectra (spectra of the first order) accompanied by some few lines. These spectra are finer than those of selenium and tellurium.

Iron and copper exhibit lines and, less prominently, bands. Manganese has a beautiful series of bands and a group of three very closely adjacent lines. Aluminium gives a fine continuous spectrum with three lines, origin uncertain, zinc a continuous spectrum without lines, and cadmium a spectrum consisting of one single line only, λ 3260.2.

Of compounds, chromic trioxide yields a continuous spectrum with six lines belonging to the metal, copper oxide a fine banded spectrum with two lines of the metal, magnesium sulphate gives a spectrum of magnesium oxide consisting of broad degraded bands composed of closely adjacent fine lines and one line belonging to the metal, λ 2852.

The sulphates of calcium, strontium and barium give both bands of the oxides and lines of the elements. Phosphorus pentoxide yields a continuous spectrum with one peculiar line, seen also in the spectrum of arsenic.

The chlorides of the alkalis give also lines of the elements with a more or less continuous spectrum, which, it is believed, is due to the metal in each case. Lithium chloride gives no continuous spectrum.

The Volatility of Metals.—One of the most interesting facts ascertained by this investigation is the volatility of all the metals examined, except platinum, and particularly the extraordinary volatility of manganese, and, to some extent, of the infusible metal iridium. Metal believed to be pure iridium is seen to have diminished after the flame has played upon it for about two hours. (Abstract of a paper read before the Royal Society, by Professor W. N. Hartley. From the *Chemical News.*)

Photography of Sun-Spot Spectra.

PRINCETON, N. J., May 23d, 1893.

MY DEAR MR. HALE:

I take the the liberty to send you some negatives of Sun-spot spectra for reproduction, if you think it worth while, in "ASTRONOMY AND ASTRO-PHYSICS." They show very fairly the widening of lines in the spectrum, but not so well the occasional narrowing of others. In the C plate [No. 135], the little line at 6573, just below C, shows well, but C itself in this spot unfortunately was not much narrowed,—not the slightest tendency towards reversal is evident. Perhaps the best of the negatives is No. 131. I have marked on the plate the approximate position of the two lines at 5727 and 5732 which are always very much widened, and have between them two other lines, which in the spot-spectrum are generally nearly as strong, though almost invisible outside of the spot itself. 5727 and the other one close to it are Vanadium lines according to Rowland.

As you will see at once the focus is good only over about one-third the length of the spectrum, and on each of the plates one of the spectra is much better than the other two. Please pick out the best ones for printing, if you determine to use them. The plates are Cramer's isochromatic, which, as you see, can be made to work clear down to B.

Mr. Reed has succeeded in getting photographs of the reversal of both C and D_3, and even photographs of a prominence seen through these lines, though nothing very satisfactory as yet. But I see no reason why, with a little more experience, he may not soon get really good pictures of the prominences as seen through C to compare with the same seen through H and K. I think they will be found to present significant differences. I send one of his D_3 pictures; but he has so far got only one or two C negatives, and I will wait until he gets something more before sending a specimen of them.

No. 130 is taken in the second order, 131 in the third, and 135 in the first,—all with the 20,000 line grating.

Yours truly,

C. A. YOUNG.

We much regret that the small scale of the photographs and the insufficient contrast renders impossible their satisfactory reproduction. The widened lines are beautifully shown, and no doubt can remain as to the value of the photographic method for recording them.

Lunar Photography with a Visual Telescope.

NAPA COLLEGE, NAPA, CALIFORNIA, May 25, 1893.

To the Editor of Astro-Physics,

DEAR SIR: I take pleasure in sending you by mail to-day a few prints and enlargements from negatives of the Moon made with the 8-inch *visual* telescope of Napa College Observatory. These photographs, excepting that of the full Moon, bear magnifying with a lens of 1-inch focal-length very well, better in fact than almost any of the Lick Observatory pictures. I hope you may find the pictures of interest and value.

Yours very truly,

ROGER SPRAGUE.

The photographs sent by Mr. Sprague are remarkably good; in fact, when it is considered that a *visual* telescope was employed, the sharp definition is surprising. An examination of these photographs might well induce any possessor of a visual telescope to undertake astronomical photography.

Observations of Comet *b* 1893.—The announcement of the discovery of a new comet in the constellation Lynx was received at this Observatory on July 10, and on the same evening the comet was observed by Professor A. O. Leuschner and myself with the thirteen-inch equatorial. It was low in the northwest, but the sky in that direction happened to be unusually free from clouds and smoke, so that a fairly good view was obtained. The coma was round, with a strong central condensation, and shaded off without any perceptible boundary into the somewhat bright background of the sky. The tail mentioned in the announcement could not be detected, but the coma on the side opposite the Sun seemed to fade a little more gradually than elsewhere, and the beginning of the tail was probably indicated by this appearance.

With a single light prism on the large spectroscope described in the January number of ASTRONOMY AND ASTRO-PHYSICS, the spectrum was at once seen to be a beautiful example of the usual hydrocarbon type. The three bands were remarkably bright and distinct, and they were connected by a narrow continuous spectrum, due to the nucleus, which extended for some distance on both sides of the bands, and exhibited a marked increase of brightness at the points of crossing. No superposed lines could be seen, nor could any other bands be certainly detected.

The bands terminated sharply on the less refrangible side, where the brightness also seemed to be greatest. This appearance was most noticeable in the middle and brightest (green) band. On narrowing the slit the edge became so bright and sharp as to resemble a narrow, bright line, like the terminal line of the corresponding hydrocarbon fluting. The second maximum of this fluting could not, however, be recognized in the cometary band.

This observation has some interest, in view of the fact that very frequently, in cometary spectra, the maximum brightness of the bands is not found at their less refrangible edges, as it always is in the artificially produced hydrocarbon spectrum.

A direct comparison of spectra was not made, and unfavorable weather has prevented measurements or any further visual observations.

It was interesting to observe how much farther the coma could be traced with the spectroscope than in the ordinary eye-piece with the eye alone. The bright sky background which in the latter case made the coma invisible at a short distance from the nucleus, was by the spectroscope spread out into a faint continuous spectrum, which did not interfere perceptibly with the visibility of the bright hydrocarbon bands. By moving the slit slowly across the image of the comet (in declination), and noting the points at which the last traces of the bands disappeared, the diameter of the coma was found to be about 9′.5, or nearly twice what it appeared to be in the eye-piece of the telescope.

Attempts were made to photograph the spectrum on July 12 and 14, through a very smoky atmosphere, and naturally without success.

This evening (July 19) we succeeded in obtaining a photograph of the spectrum of the comet, using a single prism on the large spectroscope. The exposure was two hours, but the last hour certainly counted for very little. A preliminary exposure of one minute was made on the Moon, with half of the slit covered, and the cometary spectrum was then photographed with the other half, the lunar spectrum serving to identify the lines in the spectrum of the comet when the plate was developed. For the Moon the slit-width was 0.001 inch, and for the comet 0.01 inch.

Two strong bands appeared upon the plate; one the carbon fluting at λ 472, which is the most refrangible of the three bands seen with the eye, and the other in the ultra violet, above the *K* line On account of the large slit-width the wave-lengths could be only approximately determined. The band at λ 472 was not sharply defined, and looked more like a hazy band than like a fluting. The other was sharply terminated by a line on the less refrangible side, at λ 388, and shaded away somewhat rapidly on the other. Between these two bands were perhaps some others, but they were too faint to be distinguished certainly from blotches on the film. The continuous spectrum of the nucleus was not seen on the plate, perhaps on account of the difficulty of telling when the nucleus was in the slit, in guiding the telescope.

It is easy to identify the ultra-violet band with the carbon band, or rather group of lines, photographed by Dr. Huggins in the spectrum of comet *b* 1881. Traces of doubling were even visible, corresponding to the two strongest lines on Dr. Huggins' photograph. The two groups of lines shown in Dr. Huggins' drawing in *Proc. Royal Soc.*, Vol. XXXIII, plate I., do not appear in my photograph.

July 20. The sky was clear last night and further observations were made. The nucleus was brighter than before, and the tail was conspicuous.

With the spectroscope, arranged as on July 10, the spectrum of the comet was carefully observed with special reference to the distribution of light in the bands. The lower edges still seemed to be the places of maximum brightness, but the light did not fall off rapidly toward the violet. Comparison with the flame of an alcohol lamp showed a coincidence of the cometary bands with the flutings of hydrocarbon which could be determined with much exactness in the case of the brightest band, and less satisfactorily in that of the others.

Both Professor Leuschner and I were almost certain that we could see the second maximum of the hydrocarbon fluting in the brightest cometary band, and we independently noted the two star-like points where the continuous spectrum of the nucleus was crossed by the terminal lines of the first and second maxima.

Allegheny Observatory, JAMES E. KEELER.
July 21, 1893.

The Spectrum of Comet *b* 1893 (Rordame).—The spectrum of this comet has been observed here both visually and photographically, and a large number of new bright lines have been detected.

VISUAL OBSERVATIONS.

The yellow, green and blue bands appear with their usual intensities, but their less refrangible edges seem to be completely resolvable into bright lines. Wave-lengths were determined for two lines in the yellow band, three in the green and one in the blue; and several other ill-defined lines were seen in the yellow and blue bands. A red band at w. l. 601 and violet bands at w. l. 434 and w. l. 421 are easily visible. The wave-lengths obtained are given in the following table. The fourth column contains Kayser and Runge's wave-lengths of the edges of the corresponding carbon bands.

July 11.	July 12.	July 17.	Carbon bands.	Description of bright lines and bands.
600	601		619—595	Maximum of red band broad, faint.
562	—	—	—	Red edge of yellow band.
—	—	5633	5635	Very faint line terminating yellow band.
—	—	558	5585	Bright line in yellow band.
5162.1	5161.8	5163.9	5165.3	Very bright line terminating green band.
5124	5127	5128	5129	Very bright line in green band.
—	—	509	—	Very bright line in green band.
4734	—	—	4737	Red edge of blue band.
—	—	4734	4737	Bright line terminating blue band.
—	434	—	—	Bright region in continuous spectrum, faint.
—	421	—	—	Bright region in continuous spectrum, faint.

PHOTOGRAPHIC OBSERVATIONS.

Two photographs of the region w. l. 487-387 were obtained. They show five lines in the less refrangible side of the blue band. The two violet bands observed visually at w. l. 434 and 421 are shown to consist of five and two lines respectively. The results for these plates are given below; and likewise, in the last column, the wave-lengths of the corresponding bands and lines of carbon and cyanogen as given by Kayser and Runge.

July 13.	July 16.	Carbon.	Description of bright lines.
4736.1	4736.3	4737.2	Very bright line, the head of blue band group.
4716.7	4715.2	4715.3	Very bright line, in the blue band group.
4698.1	4696.0	4697.6	Very bright line in the blue band group.
4683.4	4683.0	4684.9	Brightest line, in the blue band group.
4674.8	4675.4		Apparently a very bright line, in the blue band group, but not well separated from 4683.
455	—	—	Exceedingly faint, possibly a defect in film.
452	—	—	Exceedingly faint, possibly a defect in film.
449	—	—	Exceedingly faint, possibly a defect in film.
4366.3	4366.1	(4365.0?)	Very bright line.
4350.3	4349	—	Very faint line.
4333.9	4335.8	—	Faint line.
4313.2	4312.7	—	Very bright line.
4298.7	4298.0	—	Very bright line.
4253	426	—	Very faint line.
4235	4234	—	Very faint line.
		Cyanogen	
4214.3	4214.2	4216.1	Very bright line.
4196.7	4195.8	4197.2	Bright lines.
4178	—	4180.7	Very faint line, uncertain.
4126	—	4128.1	Faint line.
4098.0	4097.8	4099.2	Bright line.
4071.8	4073.5	4073.7	Bright line probably double, at 4075 and 4069.
4052.4	4052.2	4053.3	Bright line.
4043.9	4042.3	—	Bright line.

July 13.	July 16.	Cyanogen.	Description of bright lines.
4017.1	4021.4	—	Bright line.
4011.2	—	—	Faint line.
3988	3988	—	Very faint line.
3881.2	3881.3	3883.5	Very bright line, probably brightest in spectrum.
3870.0	3869.9	3871.5	Bright line, broad, resembles a band, more refrangible edge faint.

The agreement of the comet spectrum with the strong bands and lines in the carbon and cyanogen spectra is perfect, within the limits of error, except that the wave-lengths for the comet are systematically less by one or two tenth-metres than Kayser and Runge's results. At first I was inclined to attribute the discordance to the large flexure of the spectroscope when the great telescope is in nearly a horizontal position. But the same discordance exists also in the visual observations, which are not affected by flexure. An explanation is probably to be found in the fact that in the various spectra we have to deal with unsymmetrical bands, rather than lines. Possibly, also, the motion of the comet to or from the Earth, is sufficient to affect the results appreciably. The region w. l. 436 — 423 does not appear to have been covered by the work of Kayser and Runge.

The 36-inch telescope presents several positive disadvantages for comet spectrum work, of which I may mention two.

The ratio of focal length to aperture, 19: 1, is much larger than exists in small telescopes, and hence the latter would form much brighter images on the slit-plate than the former.

The guiding in photographic work with the long telescope is difficult with low and rapidly moving objects. W. W. CAMPBELL.

Spectrum of Comet *b* 1893.—The spectrum of this comet was observed at the Kenwood Observatory with the 12-inch equatorial on the evening of July 14, a single flint prism of 60° being used in the spectroscope. The three bands of the hydrocarbon spectrum were well seen, and were found by direct comparison to agree accurately in position with these bands in the alcohol flame spectrum. They were sharply defined on the less refrangible edge, and much brightened in the comet's nucleus, where they were crossed by a continuous spectrum. No other lines or bands were seen. GEORGE E. HALE.

Attempt to Photograph the Corona from Pike's Peak.—The method devised by myself for photographing the solar corona without an eclipse, and described in recent numbers of this journal, was tried on Pike's Peak during the latter part of June, but without success. Numerous fires in the forests surrounding the Peak sent up vast volumes of smoke, and the natural deep blue of the sky gave place to whiteness nearly as marked as that seen under ordinary conditions in Chicago. For this reason it is not considered that the method has been sufficiently tested by these experiments. The night "seeing" on the Peak was invariably very poor

GEORGE E. HALE.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR SEPTEMBER AND OCTOBER.

Mercury is morning planet during the first part of September, but rises too near sunrise to be visible to the naked eye. On the 20th Mercury will be at superior conjunction. Toward the end of October the planet will become visible in the evening twilight, just after sunset.

Venus is the bright "evening star" which is so noticeable in the west after sunset at this time. The motions of the Earth and Venus are so related now that Venus appears to recede very slowly from the Sun, and will not be in very favorable position for observation until the latter part of October. Venus will be in conjunction with the Moon, 30′ north, Sept. 12 at 11^h 19^m P. M., central time, and again, 1°49′ north, Oct. 13, 6^h 40^m A. M. On Oct. 12, at 8^h 39^m P. M. the star δ Scorpii will be seen in the same field of the telescope with Venus, the star being 13′ south of the planet.

Mars will be in conjunction with the Sun Sept. 4 and will not be visible during the following month.

Jupiter is now a very brilliant object in the morning sky. During September and October Jupiter will be in most excellent position for observation, especially during the latter half of the night. The planet is in the constellation Taurus between the Pleiades and Hyades, and is moving very slowly. It is now moving eastward, will be stationary Sept. 19, and after that will retrograde slowly. Jupiter will be in conjunction with the Moon Sept. 2 at noon, Sept. 29 at 6^h 31^m P. M., and again Oct. 26 at 11^h 12^m P. M., central time. At all of these conjunctions the Moon will pass from 4° to 5° north of Jupiter.

Saturn will be at conjunction with the Sun Oct. 8, and will therefore be invisible during the months of September and October.

Uranus will be too low in the west in the evening to be well seen. He will be in conjunction with the Moon, 2°14′ north, Sept. 14 at 12^h 55^m A. M. and again 2° 24′ north, Oct. 11 at noon.

Neptune will be at quadrature, 90° west of the Sun on Sept. 5. The position is very favorable for observation especially after midnight. It is in Taurus about 14° east of Jupiter, about 2° west and 32′ south of the 5th magnitude star ι Tauri. On Sept. 15 Neptune will be at the stationary point of his apparent path among the stars and will be very nearly in the same place during the two months of September and October.

MERCURY.

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
1893.	h m	° ′	h m	h m	h m
Sept. 5	10 11.5	+ 12 49	4 17 A. M.	11 11.4 A. M.	6 05 P. M.
15	11 22.5	+ 5 56	5 17 "	11 42.8 "	6 09 "
25	12 28.1	− 1 56	6 14 "	12 08.9 P. M.	6 04 "
Oct. 5	13 28.3	− 9 21	7 04 "	12 29.7 "	5 55 "
15	14 25.8	− 15 46	7 50 "	12 47.8 "	5 46 "
25	15 21.7	− 20 47	8 29 "	1 04.1 "	5 39 "

VENUS.

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
Sept. 5	13 01.9	− 6 16	8 24 A. M.	2 01.3 P. M.	7 39 P. M.
15	13 46.2	− 11 13	8 49 "	2 06.2 "	7 21 "
25	14 31.7	− 15 46	9 14 "	2 12.2 "	7 10 "
Oct. 5	15 18.8	− 19 43	9 40 "	2 19.9 "	7 10 "
15	16 07.6	− 22 53	10 04 "	2 29.2 "	6 54 "
25	16 57.8	− 25 04	10 26 "	2 39.9 "	6 54 "

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MARS.		
Sept. 5	10 56.2	+ 7 57	5 24 A. M.	11 58.3 A. M.	6 32 P. M.
15	11 19.8	+ 5 26	5 19 “	11 42.5 “	6 06 “
25	11 43.4	+ 2 53	5 13 “	11 26.7 “	5 40 “
Oct. 5	12 07.0	+ 0 16	5 07 “	11 10.9 “	5 14 “
15	12 30.7	− 2 23	5 02 “	10 55.3 “	4 48 “
25	12 54.5	− 4 56	4 57 “	10 39.7 “	4 23 “
			JUPITER.		
Sept. 5	3 57.0	+19 22	9 30 P. M.	4 53.9 A. M.	12 17 P. M.
15	3 58.2	+19 24	8 52 “	4 15.8 “	11 39 A. M.
25	3 58.0	+19 22	8 13 “	3 36.3 “	11 00 “
Oct. 5	3 56.4	+19 17	7 32 “	2 55.4 “	10 18 “
15	3 53.5	+19 08	6 51 “	2 13.2 “	9 35 “
25	3 49.5	+18 55	6 09 “	1 29.9 “	8 51 “
			SATURN.		
Sept. 5	12 47.1	− 2 36	7 54 A. M.	1 46.6 P. M.	7 39 P. M.
15	12 51.4	− 3 04	7 21 “	1 11.5 “	7 02 “
25	12 55.8	− 3 32	6 48 “	12 36.5 “	6 25 “
Oct. 5	13 00.0	− 3 59	6 15 “	12 01.7 “	5 48 “
15	13 04.3	− 4 26	5 42 “	11 26.9 A. M.	5 12 “
25	13 08.8	− 4 53	5 09 “	10 52.1 “	4 35 “
			URANUS.		
Sept. 5	14 22.3	−13 44	10 15 A. M.	3 21.5 P. M.	8 28 P. M
15	14 24.1	−13 53	9 38 “	2 44.0 “	7 50 “
25	14 26.0	−14 03	9 01 “	2 06.6 “	7 12 “
Oct. 5	14 28.2	−14 14	8 25 “	1 29.6 “	6 34 “
15	14 30.5	−14 25	7 48 “	12 52.5 “	5 56 “
25	14 32.9	−14 37	7 12 “	12 15.5 “	5 19 “
			NEPTUNE.		
Sept. 5	4 49.4	+20 55	10 16 P. M.	5 46.1 A. M.	1 17 P.M.
15	4 49.5	+20 55	9 36 “	5 06.9 “	12 38 “
25	4 49.4	+20 55	8 57 “	4 27.5 “	11 58 “
Oct. 5	4 49.0	+20 54	8 17 “	3 47.8 “	11 19 “
15	4 48.4	+20 52	7 38 “	3 07.9 “	10 38 “
25	4 47.7	+20 51	6 58 “	2 27.9 “	9 58 “
			THE SUN.		
Sept. 5	10 58.6	+ 6 33	5 29 A. M.	11 58.4 A. M.	6 28 P. M.
15	11 34.6	+ 2 45	5 41 “	11 54.9 “	6 09 “
25	12 10.5	− 1 09	5 52 “	11 51.4 “	5 50 “
Oct. 5	12 46.7	− 5 02	6 04 “	11 48.2 “	5 32 “
15	13 23.6	− 8 48	6 17 “	11 45.7 “	5 14 “
25	14 01.6	−12 22	6 30 “	11 44.1 “	4 58 “

Phases and Aspects of the Moon.

		d	h m	
Last Quarter	Sept.	3	3 42	A. M.
Perigee	“	4	3 30	“
New Moon	“	10	1 05	“
Apogee	“	17	8 18	“
First Quarter	“	17	10 19	P. M.
Full Moon	“	25	2 23	“
Perigee	“	29	9 48	A. M.
Last Quarter	Oct.	2	9 19	“
New Moon	“	9	2 27	P. M.
Apogee	“	15	4 00	A. M.
First Quarter	“	17	5 20	P. M.
Full Moon	“	25	1 28	A. M.
Perigee	“	27	12 30	“
Last Quarter	“	31	4 42	P. M.

Phenomena of Jupiter's Satellites.

	h	m			
Sept. 1	12	28	A. M.	II	Ec. Re.
	12	58	"	II	Oc. Dis.
	3	15	"	II	Oc. Re.
2	9	23	P. M.	II	Tr. Eg.
3	4	00	A. M.	I	Sh. In.
4	1	11	"	I	Ec. Dis.
	10	29	P. M.	I	Sh. In.
	11	50	"	I	Tr. In.
5	12	41	A. M.	I	Sh. Eg.
	2	01	"	I	Tr. Eg.
	11	09	P. M.	I	Oc. Re.
7	3	06	A. M.	III	Ec. Dis.
8	12	51	"	II	Ec. Dis.
	3	05	"	II	Ec. Re.
	3	30	"	II	Oc. Dis.
9	9	18	P. M.	II	Sh. Eg.
	9	37	"	II	Tr. In.
	11	53	"	II	Tr. Eg.
10	10	42	"	III	Tr. In.
11	12	02	A. M.	III	Tr. Eg.
	3	05	"	I	Ec. Dis.
12	12	22	"	I	Sh. In.
	1	41	"	I	Tr. In.
	2	35	"	I	Sh. Eg.
	3	52	"	I	Tr. Eg.
	9	33	P. M.	I	Ec. Dis.
13	1	00	A. M.	I	Oc. Re.
	9	03	P. M.	I	Sh. Eg.
	10	20	"	I	Tr. Eg.
15	3	27	A. M.	II	Ec. Dis.
16	9	33	P. M.	II	Sh. In.
	11	54	"	II	Sh. Eg.
17	12	06	A. M.	II	Tr. In.
	2	21	"	II	Tr. Eg.
	9	13	P. M.	III	Sh. In.
	10	57	"	III	Sh. Eg.
18	2	28	A. M.	III	Tr. In.
	3	46	"	III	Tr. Eg.
	9	28	P. M.	II	Oc. Re.
19	2	17	A. M.	I	Sh. In.
	3	31	"	I	Tr. In.
	11	27	P. M.	I	Ec. Dis.
20	2	50	A. M.	I	Oc. Re.
	8	45	P. M.	I	Sh. In.
	9	58	"	I	Tr. In.
	10	57	"	I	Sh. Eg.
21	12	09	A. M.	I	Tr. Eg.
	9	17	P. M.	I	Oc. Re.
24	12	09	A. M.	II	Sh. In.
	2	30	"	II	Sh. Eg.
	2	32	"	II	Tr. In.
25	1	13	"	III	Sh. In.
	2	57	"	III	Eg. Sh.
	9	34	P. M.	II	Ec. Re.
	9	38	"	II	Oc. Dis.
	11	53	"	II	Oc. Re.
26	4	11	A. M.	I	Sh. In.
27	1	21	"	I	Ec. Dis.
	10	39	P. M.	I	Sh. In.
	11	47	"	I	Tr. In.
28	12	51	A. M.	I	Sh. Eg.
	1	58	"	I	Tr. Eg.
Sept 28	9	00	P. M.	III	Oc. Re.
	11	06	"	I	Oc. Re.
Oct. 1	2	45	A. M.	II	Sh. In.
2	9	55	P. M.	II	Ec. Dis.
3	2	15	A. M.	II	Oc. Re.
4	8	23	P. M.	II	Tr. Eg.
5	12	33	A. M.	I	Sh. In.
	1	34	"	I	Tr. In.
	2	45	"	I	Sh. Eg.
	3	45	"	I	Tr. Eg.
	8	36	P. M.	II	Ec. Re.
	9	44	"	I	Ec. Dis.
	11	19	"	III	Oc. Dis.
6	12	32	A. M.	III	Oc. Re.
	12	53	"	I	Oc. Re.
	8	01	P. M.	I	Tr. In.
	9	14	"	I	Sh. Eg.
	10	12	"	I	Tr. Eg.
10	12	30	A. M.	II	Ec. Dis.
11	8	29	P. M.	II	Tr. In.
	9	00	"	II	Sh. Eg.
	10	44	"	II	Tr. Eg.
12	2	27	A. M.	I	Sh. In.
	3	21	"	I	Tr. In.
	4	39	"	I	Sh. Eg.
	11	07	P. M.	III	Ec. Dis.
	11	38	"	I	Ec. Dis.
	12	37	"	III	Ec. Re.
13	2	48	A. M.	I	Oc. Re.
	2	48	"	III	Oc. Dis.
	4	00	"	III	Oc. Re.
	8	55	P. M.	I	Sh. In.
	9	47	"	I	Tr. In.
	11	08	"	I	Sh. Eg.
	11	58	"	I	Tr. Eg.
14	9	06	"	I	Oc. Re.
17	3	05	A. M.	II	Ec. Dis.
18	9	17	P. M.	II	Sh. In.
	10	49	"	II	Tr. In.
	11	37	"	II	Sh. Eg.
19	1	04	A. M.	II	Tr. Eg.
	4	21	"	I	Sh. In.
20	1	32	"	I	Ec. Dis.
	3	07	"	III	Ec. Dis.
	4	25	"	I	Oc. Re.
	4	37	"	III	Ec. Re.
	8	02	P. M.	II	Oc. Re.
	10	50	"	I	Sh. In.
	11	33	"	I	Tr. In.
21	1	02	A. M.	I	Sh. Eg.
	1	44	"	I	Tr. Eg.
	8	01	P. M.	I	Ec. Dis.
	10	52	"	I	Oc. Re.
22	7	30	"	I	Sh. Eg.
	8	10	"	I	Tr. Eg.
23	7	00	"	III	Sh. Eg.
	8	07	"	III	Tr. In.
	9	20	"	III	Tr. Eg.
25	11	53	"	II	Sh. In.
26	1	06	A. M.	II	Tr. In.
	2	14	"	II	Sh. Eg.
	3	21	"	II	Tr. Eg.

Oct. 27	3 27	"	I	Ec. Dis.
	6 58	P. M.	II	Ec. Dis.
	10 18	"	II	Oc. Re.
28	12 44	A. M.	I	Sh. In.
	1 17	"	I	Tr. In.
	2 56	"	I	Sh. Eg.
	3 28	"	I	Tr. Eg.
	9 55	P. M.	I	Ec. Dis.
29	12 36	A. M.	I	Oc. Re.
	7 12	P. M.	I	Sh. In.
	7 43	"	I	Tr. In.
	9 24	"	I	Sh. Eg.
	9 54	"	I	Tr. Eg.
30	7 02	"	I	Oc. Re.
	9 14	"	III	Sh. In.
	11 00	"	III	Sh. Eg.
	11 20	"	III	Tr. In.
31	12 39	A. M.	III	Tr. Eg.

Configuration of Jupiter's Satellites at Midnight Central Time.

Sept.		Sept.		Oct.	
1	1 4 ○ 2 3	22	1 ○ 2 3 4	11	♃ 3 ○ 1 4
2	2 ○ 1 4 3	23	○ 2 1 3 4	12	2 3 1 ○ 4
3	2 1 3 ○ 4	24	2 1 ○ 3 4	13	♃ 4 ○ 2 3
4	3 ○ 1 2 4	25	3 ○ 1 4 ●	14	4 ○ 1 2 3
5	3 ○ 2 4 ●	26	3 1 ○ 4 2	15	4 2 1 ○ 3
6	2 3 1 ○ 4	27	3 4 2 ○ 1	16	4 2 3 ○ 1
7	2 ○ 1 3 4	28	4 2 ○ 1 3	17	4 3 1 ○ 2
8	1 ○ 2 4 3	29	4 1 ○ 2 3	18	4 3 ○ 2 1
9	♃ ○ 4 1 3	30	4 ○ 2 1 3	19	4 2 3 1 ○
10	♃ 2 4 1 ○	Oct.		20	4 ○ 1 2 3
11	4 3 ○ 1 2	1	4 2 1 ○ 3	21	4 ○ 2 3 ●
12	4 3 ○ 2 ●	2	4 3 2 ○ 1	22	2 1 ○ 4 3
13	4 3 2 1 ○	3	3 4 1 ○ 2	23	2 3 ○ 1 4
14	4 2 ○ 1 3	4	3 4 2 ○ 1	24	3 1 ○ 2 4
15	4 1 ○ 2 3	5	2 3 ○ 4 ●	25	3 ○ 2 1 4
16	4 ○ 2 1 3	6	1 ○ 2 3 4	26	2 3 1 ○ 4
17	2 4 1 ○ 3	7	○ 1 2 3 4	27	○ 1 3 4 ●
18	3 ○ 4 2 1	8	2 1 ○ 3 4	28	○ 2 4 3 ●
19	3 1 ○ 2 4	9	3 2 ○ 1 4	29	2 1 ○ 4 3
20	♃ 3 2 ○ 4	10	3 1 ○ 2 4	30	♃ 2 4 ○ 1
21	2 ○ 1 3 4			31	4 3 1 ○ 2

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T.		IMMERSION Angle f'm N pt.	EMERSION Washington M. T.		EMERSION Angle f'm N pt.	Duration.	
			h	m	°	h	m	°	h	m
Sept. 23	74 Aquarii	6.0	7	39	39	8	52	255	1	13
24	24 Piscium	6.1	15	42	17	16	31	276	0	49
28	δ Arietis	4.0	8	26	63	9	19	243	0	53
28	τ¹ Arietis	5.0	13	32	34	14	41	265	1	09
Oct. 1	49 Aurigæ	5.7	15	17	113	16	28	241	1	11
2	ν Geminorum	4.3	14	03	35	14	39	327	0	36
17	b Sagittarii	4.6	5	06	134	5	53	194	0	47
20	56 Aquarii	6.3	5	41	82	6	55	213	1	14
21	ψ¹ Aquarii	4.1	3	58	80	5	01	224	1	03
23	ζ Piscium	4.8	16	42	44	17	33	266	0	51
26	36 Tauri	6.0	15	48	105	16	51	227	1	03

Minima of Variable Sars of the Algol Type.

U CEPHEI.

R. A. .... $0^h\ 52^m\ 32^s$
Decl. .... +81° 17′
Period .... $2d\ 11^h 50^m$

Sept. 4	9 P. M.
9	8 "
14	8 "
19	8 "
24	7 "
29	7 "

U CEPHEI, CONT.

Oct. 4	7 "
9	6 "
12	6 A. M.
14	6 P. M.
17	6 A. M.
19	6 P. M.
22	6 A. M.
27	6 "

ALGOL.

R. A. .... $3^h\ 1^m\ 1^s$
Decl. .... + 40° 32′
Period .... $2d\ 40^h 49^m$

Sept. 15	3 A. M.
17	midn.
20	9 P. M.
23	6 "
Oct. 5	5 A. M.
8	2 "

ALGOL, CONT.

Oct. 10	11 P. M.
13	8 “
28	4 A. M.
30	midn.

λ TAURI.

R. A. .... $3^h\ 54^m\ 35^s$
Decl. .... $+ 12° 11'$
Period .... $3d\,22^h\,52^m$

Oct. 18	6 A. M.
22	5 “
26	3 A. M.
30	2 “

R. CANIS MAJORIS

R. A. .... $7^h\ 14^m\ 30^s$
Decl. .... $- 16° 11'$
Period .... $1d\ 3^h\ 16^m$

Sept. 1	4 A. M.
9	3 “
10	6 “
17	2 “
18	5 “
26	4 “
27	7 “
Oct. 4	3 “
5	6 “
12	2 “
13	5 “
21	4 “

R. CANIS MAJ, CONT.

Oct. 22	7 A. M.
29	3 “
30	6 “

U CORONÆ.

R. A. .... $15^h\ 13^m\ 43^s$
Decl. .... $+ 32° 03'$
Period .... $2d\ 10^h\ 51^m$

Sept. 8	midn.
15	10 P. M.
22	7 “
Oct. 23	9 “
30	7 “

U OPHIUCHI.

R. A. .... $20^h\ 47^m\ 40^s$
Decl. .... $+ 34° 15'$
Period .... $1d\ 11^h\ 57^m$

Sept. 1	10 P. M.
2	6 “
6	10 “
7	6 “
11	11 “
12	7 “
17	8 “
22	8 “
27	9 “
Oct. 2	10 “
3	6 “
7	11 “

U OPHIUCHI, CONT.

Oct. 8	7 P. M.
13	8 “
18	8 “
23	9 “
29	10 “
30	6 “

Y CYGNI

R. A. .... $20^h\ 47^m\ 40^s$
Decl. .... $+ 34° 15'$
Period .... $1d\ 11^h\ 57^m$

Sept. 2	3 A. M.
5	3 “
8	3 “
11	3 “
14	3 “
17	3 “
20	3 “
23	2 “
26	2 “
29	2 “
Oct. 2	2 “
5	2 “
8	2 “
11	2 “
14	2 “
17	2 “
20	2 “
23	2 “
26	1 “
29	1 “

COMET NOTES.

Comet *b* 1893.—The account of the discovery of this comet and description of its appearance is given by Professor Payne on page 596. The elements of its orbit thus far computed indicate that it is a new comet and that the orbit does not differ appreciably from a parabola. We have at hand three sets of elements, the first by Professor Boss from observations at Cambridge July 10 and Cincinnati July 11, and a rough observation at Albany July 16; the second by Professor Porter from his own made July 10, 13 and 16; the third by Leavenworth and Wilson from observations at Cambridge July 10 and Northfield July 12 and 14. The last, although depending on shorter intervals of time, appears to be the most accurate, and represents an observation made here July 21 within less than 1′. We have therefore computed the following ephemeris from elements III:

Elements of Comet b, 1893.

	I	II	III	
	Boss.	Porter.	Leavenworth and Wilson.	
T	$= 1893$, July 7.7520	July 7.3766	July 7.2429 Gr. M. T.	
ω	$= 46° 54'$	$47° 05'.2$	$47° 11' 24''$	} 1893.0
Ω	$= 335\ 56$	$337\ 02\ .2$	$337\ 29\ 17$	
i	$= 159\ 53$	$159\ 55\ .6$	$159\ 59\ 08$	
$\log q$	$= 9.83136$	9.82936	9.828890	
C — O	$\Delta\lambda_2 \cos \beta_2 - 0'.5$; $\Delta\beta_2 - 0'.7$		$\Delta\lambda_2 \cos \beta_2 + 9''$; $\Delta\beta_2 + 8''$	

Ephemeris of Comet b, 1893.

Berlin Midn.	R. A.			Decl.		log *r*	log *ρ*	Br.
	h	m	s	°	′			
Aug. 1.5	12	00	58	+ 15	38.3	9.9294	0.0593	0.088
5.5	12	06	23	13	39.8	9.9542	0.1117	0.062
9.5	12	10	25	12	04.8	9.9788	0.1570	0.045
13.5	12	13	38	10	46.9	0.0033	0.1964	0.033
17.5	12	16	16	9	41.2	0.0269	0.2308	0.025
21.5	12	18	36	8	44.4	0.0497	0.2611	0.020
25.5	12	20	42	7	54.4	0.0718	0.2881	0.016
29.5	12	22	40	7	09.8	0.0929	0.3120	0.013
Sept. 2.5	12	24	32	6	29.4	0.1132	0.3334	0.011
6.5	12	26	20	+ 5	52.4	0.1326	0.3525	0.009

The brightness of the comet on July 10 was taken as 1.00.

From this ephemeris it is apparent that the comet is rapidly receding from the Earth and therefore diminishing in brightness. It will probably not be observable in September because of its faintness and the presence of strong twilight.

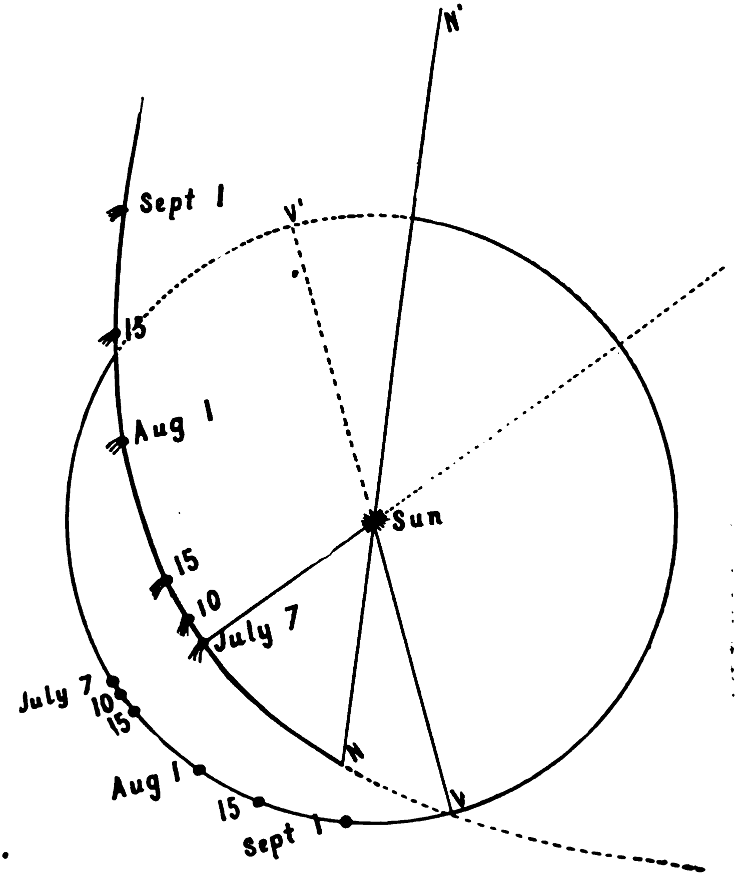

DIAGRAM SHOWING RELATIVE POSITIONS OF COMET *b* 1893 AND THE EARTH.

The accompanying diagram will give the unscientific reader some idea of the relation between the paths of the comet and Earth. Suppose the circle represent ing the Earth's orbit to lie in the plane of the paper, then the comet's path lies in a plane inclined 20° to that of the paper and intersecting the latter in the line NN′ which is called the line of nodes.

About June 26 the comet passed the point N, its ascending node, and since that time its path has been north of the ecliptic. On July 7, it reached its nearest point to the Sun, and at almost the same time its nearest point to the Earth. It was discovered therefore at the time of its greatest brightness, when it was almost directly between the Earth and the Sun but at some distance above the line joining the two. The tail of the comet was directed toward a point almost directly over the Earth.

The apparent motion of the comet among the stars was very rapid because of its nearness to the Earth. This has been rapidly decreasing as might be expected from the fact that the Earth and comet are moving in opposite directions. Its course has been southeastward passing by the feet of the Great Bear and between Leo and Coma Berenices. During August it will move very slowly southeast from a point 5° east of the star β Leonis toward the double star γ Virginis.

Photographs of Comet *b* 1893. The comet was so low in the northwest that its position was quite unfavorable for photographs, but fairly successful exposures were made at Goodsell Observatory on the nights of July 11, 14, 18, 19 and 20. The instruments used were the 8-inch Clark refractor with third lens, 5-inch guiding telescope and camera with 2½-inch Darlot lenses and about eight inches equivalent focus. The camera with a 4×5 plate covers a field of about 30° diameter of which 20° is fairly well defined. The plate of July 11, reproduced in our frontispiece, was exposed 45 minutes and shows the comet's tail to a length of 12°, where it runs off the plate. It resembles very much Mr. Barnard's photographs of Swift's comet of 1892, in the number and irregular patchy appearance of the streamers. On July 14 we attempted to make two successive exposures of 40^m duration each, for the purpose of detecting rapid changes. Unfortunately the first plate proved to be bad and the atmosphere was so thick for the second that very little of the tail is shown on either plate. The photographs taken on the subsequent dates show remarkable changes in the structure of the tail. The plate of July 18 shows the tail to a distance of about 8° from the head. There are three streamers leaving the head and the middle one, which is the most prominent, afterward divides into four. On July 19 the same, or similar, three streamers are shown, but much fainter and considerably changed in structure. The length is about 7°. On the 20th but one streamer 5° in length is shown.

The photographs with the 8-inch telescope show but little of the tail of the comet. On July 11 and 14 the nucleus, or rather the condensation about the nucleus, is shown large and hazy. In the later photographs it is more starlike. On the plate of July 11 the width of the tail as it leaves the head is nearly as great as the diameter of the coma. Later it is much narrower.

Comet Rordame.—Rordame's comet has been observed here on every clear night since its discovery, when it could be seen.

Position observations, photographs and measures of light have been taken The comet when seen at its best had a tail which could be traced for some 10 or 11 degrees, although it has never been particularly brilliant. The head of the comet appears as a hazy star to the naked eye, and when last seen on July 14 under fairly good conditions, was of the 3d magnitude, being almost exactly equal to α Ursæ Majoris, which by the Harvard Photometry, is 3.1. A few nights before it was estimated as 3.5 magnitude from a comparison with ι and κ Ursæ Majoris, both being H.P. stars.

In the telescope the comet has a nucleus which is quite stellar in appearance, surrounded by a bright coma which, however, fades off somewhat rapidly. While the head of the comet seems a little brighter than at first, the tail is steadily diminishing in brightness and length. On July 14 it was rather faintly seen with the naked eye, extending for a distance of some over 2 degrees and nearly vertically.

The rapid easterly motion of the comet at first, together with the diminishing twilight, seemed to indicate that the comet might soon be seen to better advantage, but this easterly motion is slowing up, and if, as the orbital calculations show, the comet is about passing perihelion and also receding from the Earth, it seems probable that ere long it may cease to be visible to the naked eye.

O. C. WENDELL.

Harvard College Observatory, July 15, 1893.

Rordame's Comet.—The first intelligence of the appearance of the comet received here was through the daily press, on July 10. The evening of the same day the sky was very clear but the entertainment of visitors—to whom this Observatory is open on every clear evening—prevented me from obtaining an observation of the comet until 10:45, when the circle readings gave for its approximate place R. A. $8^h\ 35^m$, + 46° 59′. At intervals during the earlier part of the evening I had picked it up with the naked eye, as had likewise the good wife and daughter, Anna, who had been watching for it from the verandah of the house. To the naked eye the comet appeared like a star of the 4th magnitude surrounded with nebulosity, and a tail, in the main straight, but curved slightly at the end, five or six degrees in length was easily seen. In the 10-in. telescope the head of the comet appeared large with bright condensation but not stellar. The tail was faint and narrow near the head about half the width of the head, and was brighter on the southern side.

The next night, July 11th, the nucleus was somewhat stellar and on July 14 decidedly so, as it was also last night.

On the evening of July 15th there was a fine aurora and the comet showed itself faintly through the auroral glow. One fine feature of this aurora was a magnificent beam or trail of greenish white light streaming upwards from the western horizon past the zenith. The beam was narrow near the horizon and grew much wider near the zenith. It indeed resembled a gigantic comet of the greatest brilliancy, for which it was mistaken by many persons.

WILLIAM R. BROOKS.

Smith Observatory, Geneva, N. Y., July 19, 1893.

Photographs of Comet *b* 1893. During the period of its greatest brightness, I have secured a number of photographs of this comet, using the Crocker telescope of the Lick Observatory. The objective of this telescope is a portrait lens of nearly six inches aperture and of about 31 inches focal length. The plates were 8 × 10 inches, coated with an unusually sensitive emulsion by Cramer (Emulsion No. 6715).

The nucleus of this comet, in all the plates, is bright and star-like. The coma is dense and nearly circular, having a diameter of about ¼°. It has short and very faint extensions in directions at right angles to the tail. The tail has been very bright. So far as these observations extend, it was brightest Thursday evening, July 13. It could then be traced, with the naked eye, fully twelve degrees. In most of the photographs it extends beyond the limits of the plates used, and, from night to night, exhibits marked and interesting changes. Some of these will be noted.

Tuesday, July 11, 9^h 00^m to 9^h 20^m. This negative shows the comet with a multiple tail. Four distinct branches proceed from the nucleus. The angle included between the outermost branches is approximately 30°. The middle branches are much the brightest, and at some distance from the nucleus they divide into numerous streamers.

Wednesday, July 12, 9^h 00^m to 10^h 12^m. Four distinct branches of the tail spring from the nucleus and include an angle of about 40°. The central ones are the brightest. The northernmost one is short, 1½° long, and very gradually diminishes in brightness as the distance from the nucleus increases. The one next to it is bright and nearly straight, broadening a little as the distance increases, and fading away at about 7°. The next is the brightest of the branches and the most complicated in structure. It is composed of numerous streamers, which in places appear to be interlacing and in others to offer a somewhat doubtful suggestion of an outward spiral motion. (This is also the case with the photograph of Tuesday, July 18). Fully 9° of this branch is shown on the plate. The remaining branch is short and without special interest.

Thursday, July 13, 9^h 10^m to 10^h 20^m. The tail has a complicated structure. In it there are several condensations. The distances of the principal ones from the nucleus are approximately 1°.4, 1°.8, 3°.6 and 6°.0. The second of these is much the brightest. It and also the third are sources of secondary streamers, which give the tail a peculiar appearance, somewhat resembling that shown in Professor Barnard's photographs of Swift's comet of last year. All the condensations belong to the central parts of the tail. In the neighborhood of these condensations the streamers are strongly curved. In the other branches they are very straight and the spaces between them unusually clear. The changes have been so great since last night, that the four divisions of the tail, which were then so distinct, are not easily recognizable now.

Friday, July 14, 9^h 08^m to 10^h 28^m. The tail can be traced 12° on the plate. The peculiar condensations of last night have very nearly disappeared. Throughout, the tail is very much fainter and its brightness diminishes very gradually. Near the coma, there are seven distinct divisions of the tail. Excepting the central ones, they are straight and short.

Saturday, July 15, 8^h 45^m to 9^h 30^m. Near the coma the tail has several branches of which the central one is brightest, and excepting it, they are very straight. The central branch divides at about 1° from the nucleus, and near this point the streamers composing it are strongly curved. At 6° from the nucleus the tail is about 1° broad.

Sunday, July 16. The description for last night answers very well for the negative of to-night.

Tuesday, July 18, 9^h 01^m to 10^h 21^m. In contrast with all the previous photographs, the tail is single near the nucleus and very narrow. It widens slowly. At a distance of 1° from the nucleus it divides and the divisions of the tail are formed. The principal branches are unequally bright along their course.

Stanford University, Cal. W. J. HUSSEY.
July 21, 1893.

Comet 1892 VI (Brooks Aug. 28).—This comet was observed here June 12, when it was described as small, round, 20″ in diameter, strongly condensed in the center, 10 magnitude, so that it was quite easy to observe with the 16-inch. It was barely visible with the five-inch finder.

On July 18, a very faint patch of light was seen just 5′ south of the 8 magnitude star S.D.M. — 20°, 4646, the resulting position being R. A. 17^h 02^m 23^s; Decl. — 20° 06′. It was impossible to get a micrometer measurement.

Finlay's Comet.—This comet is in the constellation Taurus near the star ζ. It will during August move eastward into the center of the constellation Gemini. It rises from three to four hours before the Sun, but is in pretty strong twilight when it is high enough to observe, so that it is seen with difficulty.

Ephemeris.

1893		α app.			δ app.			log Δ.	Aberration.	
		h	m	s	°	′	″		m	s
August	5	5	38	7.92	+ 22	48	17.3	0.14265	11	34.2
	6		42	4.43	22	52	51.7	14450		37.2
	7		45	58.93	22	57	2.1	14634		40.1
	8		49	51.40	23	0	48.9	14916		43.0
	9		53	41.82	23	4	12.8	15097		45.9
	10	5	57	30.17	23	7	14.3	15275		48.8
	11	6	1	16.43	23	9	53.9	15451		51.7
	12		5	0.59	23	12	12.3	15625		54.5
	13		8	42.62	23	14	10.0	15797	11	57.3
	14		12	22.52	23	15	47.6	15966	12	0.1
	15		16	0.28	23	17	5.8	16133		2.9
	16		19	35.89	23	18	5.1	16299		5.7
	17		23	9.34	23	18	46.0	16462		8.4
	18		26	40.63	23	19	9.2	16623		11.1
	19		30	9.75	23	19	15.2	16781		13.8
	20		33	36.70	23	19	4.4	16936		16.5
	21		37	1.49	23	18	37.5	17089		19.1
	22		40	24.12	23	17	55.1	17239		21.6
	23		43	44.59	23	16	57.6	17387		24.1
	24		47	2.91	23	15	45.7	17532		26.6
	25		50	19.07	23	14	19.9	17674		29.0
	26		53	33.06	23	12	40.6	17813		31.4
	27		56	44.90	23	10	48.5	17949		33.8
	28	6	59	54.59	+ 23	8	44.1	0.18082	12	36.1

NEWS AND NOTES.

Subscribers will please remember that this journal does not appear for the month of September, that is our second vacation month.

All persons hereafter paying bills due this journal, on account of subscription or advertising, will please make remittances either by post office order, or note, or registered letter, or bank draft. This change on our part is due to the action of banks in the cities near us restricting the use of personal checks.

Honor to Mr. Proctor's Memory.—It will be remembered that the late Richard A. Proctor, known everywhere as one of the distinguished astronomers of the present century, resided in St. Joseph, Mo., for several years, then in Florida, at which place he contracted the yellow fever, as he was about starting for a trip to Europe. He reached New York and suddenly died there from the above named disease. His remains came into the hands of the undertaker who interred them in his own lot. Edward W. Bok, editor of the *Ladies' Home Journal*, Philadelphia, visited Professor Proctor's resting place in Greenwood Cemetery, Brooklyn, and found it sadly neglected.

He at once called public attention to the matter, and personally consulted with Mr. George W. Childs, the well-known philanthropist and editor of the Philadelphia *Ledger*, on the propriety of raising a fund for the purchase of a suitable lot and the erection of a monument to the memory of one whose reputation in the literary and scientific world was as wide as civilization. Mr. Childs has concluded to himself furnish the necessary means to purchase an eligible lot in Greenwood cemetery and erect a monument to the memory of Professor Proctor, and has authorized Mr. Edward W. Bok to at once carry out his purpose, so no public subscription will be necessary.

Mr. Childs has in his long career performed many noble and charitable acts, but few, we think, that will redound more to his honor.

The daughters of Professor Proctor, Miss Mary and Miss Agnes, who are highly esteemed and honored by St. Joseph people, are especially grateful to Mr. Childs for his generous act.

They are joined in this token of deserved gratitude to Mr. Childs by the large circle of friends and admirers of Mr. Proctor in all the scientific world.

Investigation of the Nautical Almanac Office at Washington.—An investigation of the conduct of the Nautical Almanac Office by Professor Simon Newcomb, which has recently been concluded at Washington, is so unique in some particulars that a brief account of it will not be without interest. The complainant in the case was Dr. Joseph Morrison, who has been the best known of Professor Newcomb's assistants in the preparation of the American Ephemeris since 1881. His principal duties were those of superintending the printing and seeing that all necessary precautions to guard against error were taken. It appears, however, that Professor Newcomb has recently become dissatisfied with the way in which he performed his duties, and last spring requested his resignation. This was refused, and soon after the present administration came into power, Professor Newcomb wrote to the Secretary of the Navy recommending his dismissal. As this communication forms no part of the case under investigation, we cannot state more exactly what the complaint against Dr. Morrison was. The latter responded by writing a very long letter to the Secretary, not only defending himself with great vigor, but making numerous complaints of the management of the office by the superintendent. The following extracts from the letter will not be without interest:

"I am a graduate in arts, medicine and science of three different universities in this country, as well as of a foreign university, and the author of several works and papers on mathematics and astronomy which are well known on both sides of the Atlantic. In 1884 I was elected a fellow of the Royal Astronomical Society of England, a higher position than Professor Newcomb has in that learned society, although I never was in England, nor did I then, nor do I now, know a single individual in the British Islands. I am also a member of other foreign scientific societies. In 1885, when the National University here was re-organized, with President Cleveland as Chancellor, I was appointed professor of chemistry and toxicology, because I am well known in the medical profession as a chemist, having had a long experience in teaching chemistry. When the Civil Service Commission requested the Secretary of the Navy to select an examiner or member of the board for the examination of those who came under the classified service in all the scientific "bureaus of the Government," such as the Coast Survey, Naval Observatory, etc., I was honored with their confidence and made presiding officer of the Board. I was finally obliged to resign from that board in consequence of the interference of Professor Newcomb with my examination papers, over which he has no control whatever."

The principal complaints against Professor Newcomb were that he had employed the doctor to write several chapters of a mathematical text-book during office hours; that he had charged mistakes against Dr. Morrison for which other computers were responsible; that he had viciously attacked him for correctly stating that the ephemeris of Saturn's satellite had been computed from Professor Hall's tables; that Mr. Loomis, another assistant, had to do only fifteen or twenty minutes' work daily, though he had once attempted to compute the Moon culminations by formulas prepared by the superintendent, which were the most extraordinary productions of a mathematician that ever came under his notice, because each culmination was made to depend on the preceding; that Mr. Loomis was found unable to do the work; that Professor Newcomb had also been guilty of "base treachery" in preventing Dr. Morrison from getting a professorship in a western college; that he spent much of his time at the Johns Hopkins University teaching mathematics and astronomy, to the utter neglect of the Nautical Almanac; that an undue proportion of the office force was spent on certain "Astronomical Papers," about which "you will look in vain for any favorable comment in the foreign scientific journals;" that Dr. Morrison had been unjustly held responsible for errors in the Almanac which were due solely to the fact that he was not furnished with sufficient assistance in making the necessary computations, etc., etc. Dr. Morrison also claimed that since he had been supervising the printing of the Ephemeris, it was freer from errors than the *Berliner Jahrbuch* or the *Connaissance des Temps*.

After some delay secretary Herbert wrote to Dr. Morrison making some remarks upon the case, and requesting his resignation. This letter also was kept out of the case so that we cannot state its contents. It appears, however, to have contained some expressions not to Professor Newcomb's liking, as it called out the following letter from him to the secretary:

NAUTICAL ALMANAC OFFICE, NAVY DEPARTMENT,
Washington, D. C., June 21st, 1893.

SIR:—In a letter of June 15th, addressed to Dr. J. Morrison, Assistant in this office, you refer to certain counter-charges made by him against Professor Newcomb, which appear to you more or less grave. I respectfully request as a matter of justice to all concerned, that you cause these charges to be thoroughly investigated, in such way and by such agency as you may deem best calculated to bring out all the facts to which they relate.

Very respectfully, your obedient servant,
S. NEWCOMB.
Professor U. S. Navy, Supt Nautical Almanac.

This request was immediately complied with, and Captain McNair, the Superintendent of the Naval Observatory was ordered to make the necessary investigation, with power to send for persons and papers, and examine witnesses under oath. The accounts of the proceedings which we have seen are both meager and uninteresting, and the whole testimony may be summed up by saying that Professor Newcomb denied *in toto* all of Dr. Morrison's allegations so far as they reflected upon his administration of the office. The most comical part of the inquiry was an investigation of the motion of the ecliptic by the methods of a court of law. Dr. Morrison had claimed that certain formulas given him by the superintendent for computing the position of the ecliptic in 1600, and 2100 relative to the ecliptic of 1850, must necessarily be wrong, because they showed a motion of the ascending node amounting to nearly 180 degrees which was impossible in 500 years. Professor Newcomb retorted thnt he wanted no better proof of the obtuseness for which he had reported Dr. Morrison than this. The Doctor insisted on expert evidence, and called in Professor Harkness, who however sustained the correctness of Professor Newcomb's formula. At latest advices, the investigation has just been concluded, but the report of Captain McNair's conclusions will probably not be known until after we go to press with the present number.

Columbia College Lectures on "Celestial Mechanics."—Professor J. K. Rees' department of Geodesy and Practical Astronomy at Columbia College, New York City, informs us that arrangements have been made for an extended course of lectures on the general subject of Celestial Mechanics, to be given by Dr. G. W. Hill, member of the National Academy of sciences, Honorary doctor of sciences of the University of Cambridge, England, etc.; that this proposed course will begin about October 14, and continue on Saturdays. These lectures are free and the course will consist, probably at least, of thirty in number. They will be confined to the motions of the heavenly bodies considered as material points, and Dr. Hill thinks it probable that he will not be able to present the whole subject during the remaining months of this year. He prefers to give a somewhat full discussion of the theme rather than a rapid *resume* of it. Short numerical illustrations will be given enabling the hearer to comprehend the bearing of the principles to be applied in practical work.

Dr. Hill has himself kindly furnished the following as a statement of the divisions of his lecture course:

I. General Equations of Dynamics.
II. Derivation of Gravitation from Phenomena.
III. Differential Equations of a System under the action of Gravitation.
IV. The Theory of Elliptic Motion.
V. Perturbations as Variations of Coördinates
VI. Perturbations as Variations of Elliptic Functions.
VII. Hansen's Method.
VIII. Delaunay's Method.
IX. Gylden's Method.
X. Development of the Perturbative Function.
XI. Secular Perturbations in Particular.
XII. The Lunar Theory in Particular.
XIII. The Theory of the Satellites.
XIV. Stability of the Motion of Planetary Systems.

The Columbia people may consider themselves fortunate in being able to secure Dr. Hill for such a course of lectures, and we congratulate Professor Rees on the inception of such a plan of instruction. He has certainly attacked a hard phase of mathematical astronomy for the student, in a wise and most effective way.

Astronomy in Current Periodicals.—*Knowledge* is one of the best periodicals of its kind in the English language. Those interested in the progress of Astronomy and kindred topics will always find its pages well filled with late and useful information. In the July number will be found a full page exquisite engraving of the central portion of the Moon when 136 hours old. It is by the direct photo-engraving process from a photograph taken by MM. Paul and Prosper Henry, with the 13-inch refractor, at the Paris Observatory, March 23, 1893. The sensitive plate was placed behind the eye-piece which enlarged the image in the principal focus sixteen times. The center of the plate shows the region between *Mare Nectaris* and *Mare Tranquilitatis*. *Mare Fecunditatis* is also partly seen and there are more than fifty other lunar objects in the area shown that may be recognized by those acquainted with the surface markings. Mr. Ranyard's accompanying article on the "Great Plains of the Moon gives a cut showing the principal features in outline, with their names, and explanations of the varied phenomena that will certainly interest any reader. Mr. Sadler's "Face of the Sky" is always very helpful for those who would know about important current celestial phenomena.

The Physical Review is a new publication issued bi-monthly at $3 per year, and is published for Cornell University by Messrs. Macmillan & Company, of New York City and London. Its editors are Edward L. Nichols and Ernest Merritt, of Cornell University, Ithaca, N. Y. Its first number is for July and August and has 80 pp. of original matter devoted to experimental and theoretical physics. The beginning of this new periodical is a very auspicious one in every way and it certainly has a field of usefulness before it.

The particular article that will interest astronomers is the "Relation between the Lengths of the yard and the meter," by Professor William A. Rogers, Shannon Physical Laboratory, Colby University This important article is supplemental to one found in the Proceedings of the American Academy of Arts and Sciences, for 1882-83, Vol. XVIII. This paper repeats the points in the earlier one, which are valuable as a piece of history of our most common standard, in showing how it was obtained, its probable error, and its relation to other important units of measure. Professor Rogers' work in metrology is an acknowledged authority in this country and abroad.

The Observatory for July contains a noble plate, as frontispiece, of Charles Pritchard, D. D., late Savilian Professor of Astronomy and Director of the University Observatory of Oxford. A biographical sketch is given elsewhere.

Professor E. E. Barnard, of Lick Observatory was present at the meeting of of the Royal Astronomical Society, June 9, 1893, and being called upon, spoke at length, as reported in the *Observatory*, having for his theme, "Photographs of the Milky Way, Comets and other Celestial Objects." His fine pictures were projected on a screen as he described them. A hearty vote of thanks was given Mr. Barnard by the society for his address.

In this number Mr. W. F. Denning describes some characteristics of the Lyrid shower of meteors, also those of Virginids and Aquilids, and Mr. Thos. Gwyn Elger gives full account of the enlarged negative of the lunar Appenines, presented by Professor E. S. Holden, of Lick Observatory.

Publications of the Astronomical Society of the Pacific. No. 30 of Vol. V. is one of the most valuable publications of the society, so far as the illustrations are concerned. The full page plate giving a curve representing the varitions of latitude at Waikiki, Hawaiian Islands, latitude 21° 16′ 24″, covers a period of observation from June, 1891, to July, 1892. The maximum change in that period is about 0″.6. The accompanying article was prepared by E. D. Preston of the U. S. Coast and Geodetic Survey. There are also given four other full page plates, showing the drawings of the surface markings of Mars by Professor Hussey and Professor Schaeberle.

We have been accustomed, in the United States, to speak of Mr. Common's five-foot reflector as if he had made only one speculum of that size. In reality he has ground three of that set. The first of these was found to be defective from faulty glass. The second proved of excellent figure. Another five-foot disc falling into his hands, he proceeded to grind and figure it. In the mean time, being asked to contribute something for exhibition at the World's Fair, he sent speculum No. 2 to Chicago and proceeded to finish No. 3 for his photographic work. This, however, has proved a difficult task and by the middle of June, though the speculum was fairly satisfactory, he decided to regrind and refigure it.

A visit to Dr. Common's home at Ealing, a beautiful suburb of London, is fraught with great interest, and one is impressed with the remarkable mechanical genius that has enabled him to produce his great instruments. This mechanical ability is inherited by a young son of Dr. Common's, who is just now finishing an exquisite working model of an English locomotive.

At a recent visit to Ealing a number of excellent negatives of the great Nebula of Orion, that had been made by five-foot No. 2, were examined. Several of these were remarkably beautiful. The intricate structure of the bright portion of the nebula was brought out in a marvelous manner, while the great looped extensions were also beautifully shown. These negatives did not present the usual 'burnt out' appearance so frequently shown in the bright region of the nebula with long exposures. Every minute detail was clearly shown, up to and about the trapezium. The star discs, though somewhat deformed by irregular 'following' in some of the negatives, indicated a good definition of the mirror. To successfully use these great mirrors, however, takes a mechanical genius and patience not excelled, perhaps, by that required to make the reflector itself.

For photographic work, for such objects as nebulæ, it is a mistake to suppose that these mirrors are not a splendid success.

The new 28-inch Grubb refractor for the Royal Observatory at Greenwich is finished and is now mounted.

It seems regretable that it was necessary to mount this large instrument on the old 12-inch mounting. The focus, 28 feet, is very short for the aperture. The object-glass was figured from curves computed by M. Christy, and is to be photographic as well as visual. By reversing the crown lens the objective is turned into a photographic instrument. It is to be used by Mr. Maunder for spectroscopic observations. The diameter of the dome for this instrument is larger than its sustaining walls, and it has somewhat of a balloon shape, and looks rather oriental.

The photographic zone work of this Observatory is progressing very satisfactorily, a large portion of the zone being already covered.

An examination of some star trails made at Greenwich seems to show that excellent definition is obtained there. This is borne out also by the statements concerning its visual observations. One specially pleasing thing about this great English Observatory is the number of young ladies employed there in the reduction of the work—resembling Harvard College Observatory in this particular.

Among the many interesting things presented at the Royal Astronomical Society rooms is the reflecting telescope with which Sir Wm. Herschel discovered the planet Uranus. It has a very singular mounting and looks extremely antiquated. This telescope produces a reverential feeling, however, and memories of the noble work of Herschel and his sister come upon you as you look at it. The redoubtable Captain Cook's sextant is also preserved in the same room with Herschel's telescope.

The Ninth Regular Meeting of the Baltimore Astronomical Society (Astronomical section Maryland Academy of Science) took place at the Maryland Academy of Science on the evening of June 13.

Meeting called to order at 8:15, President Gildersleve presiding.

Minutes of last meeting read and approved. The lecturer of the evening, Mr. Sullivan Pitts, spoke upon The Stars, their magnitudes and distances, distribution of stars and the constellations. Mr. Pitts also exhibited a model that he made, illustrating the joint motion of the Moon and Earth around the Sun.

Reports of observations were then received. Mr. Gildersleve reported spots upon the Sun on all days admitting of observation, and during twenty-three (23) days preceding the meeting there was no day upon which there were not spots upon the Sun. He also called attention to three groups of spots which admitted of continuous observation. Dr. Hooper made statements regarding time of day at which definition of Sun spots was at its best, and gave as his experience that the afternoon was much better than morning. and stated that in the afternoon the atmosphere was much more quiet than in the morning. This statement was partly corroborated by some of the members.

Reports on the Moon and planets and double stars were then in order. Dr. Hooper reported day observations of Venus. Ten minutes were then devoted to general conversation, after which Dr. Hooper (Chairman of Committee on Instruction) appointed Captain Hooper as lecturer for the next meeting, his subject being Nebulæ. Meeting then adjourned to second Tuesday in July.

J. STAHN, Sec'y.

Old and New Astronomy.*—In the preface Mr. Ranyard explains the circumstances under which this work was written. It seems that it was planned by Mr. Proctor many years ago, but financial losses compelled him to give his entire attention to more popular writing and to lecturing. Meanwhile he continued to gather material for the work, and in 1887 its publication was announced. At the time of Mr. Proctor's sudden death in 1888 Part VI had been issued, Part VII was in type, and the chapters on the planets were in manuscript. At this point Mr. Ranyard took up the work, revised the chapters on the planets and completed the book by an exhaustive discussion of the various theories of the Milky Way and the distribution of stars and nebulæ.

Chapter I, on "Ancient and Modern Methods of Observing the Heavenly Bodies," deals in an interesting way with the beginnings of the science. The Egyptologist is informed with some warmth that in questioning the astronomical character of the Great Pyramid he is trespassing outside of his province, and "his opinion is no longer of weight." The ancient observatories at Benares and Delhi are well illustrated and described, as are the instruments of Tycho Brahe and Huyghens. Modern apparatus is then taken up, and the chapter concludes with a full page cut of the 23-inch refractor of the Halsted Observatory. The second chapter on "Ancient and Modern Studies of the Earth's Shape," offers enough proofs of curvature to convert even the most rabid believer in a "flat Earth." Twenty pages are devoted to a discussion of projection and map-drawing, which will be of interest and value to the amateur astronomer. In the succeeding chapter the Sun's apparent motion among the stars is traced in a series of twelve zodiacal maps, and the apparent motions of the Moon and planets are illustrated and clearly described. Chapters IV and V, on "The True Mechanism

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* "Old and New Astronomy," by Richard A. Proctor, completed by A. Cowper Ranyard; Longmans, Green & Co., 1892.

of the Solar System," and "Measuring and Weighing the Solar System." are well adapted to the uses of the general reader. Kepler's laws, problems relating to the Moon's motions, the tides, precession and nutation, the Foucault and gyroscope proofs of the Earth's rotation, methods of determining the lunar and solar parallax and the velocity of light, the discovery of Neptune, etc., are explained with but slight appeal to mathematics. The Sun and its surroundings, as well as the principles of spectrum analysis, are dealt with in the two following chapters. Little fault can be found with the descriptive matter, but we imagine that few spectroscopists will assent to Mr. Proctor's explanation of Sun-spots, though the author remarks that it "may be considered established." It is unnecessary to enumerate here the reasons on which is based the conclusion adopted by most spectroscopists, that downward, rather than upward, motions predominate in Sun-spots. Mr. Proctor holds that spots are formed by outrushes of matter which is cooled by expansion. In prominences "the luminous jets and streaks of hydrogen are no more to be regarded as themselves the products of ejection than the luminous streaks behind advancing meteorites are to be regarded as themselves projected through the air" (p. 401). The rays and streamers of the outer corona are attributed to meteoric and cometic matter.

Chapters VIII to XVI inclusive are devoted to the planets and asteroids. In the concluding chapter of 125 pages on "The Stars" we recognize Mr. Ranyard's hand, and are relieved by the absence of the frequently bitter personalities which disfigure the preceding portion of the work. Admirable photogravure illustrations from original photographs of stars and nebulæ, duplicates of which have already delighted the readers of *Knowledge*, are of great value in connection with the text. In the discussion of stellar distribution many novel and valuable ideas are introduced. Rather than assume the existence of dark branching structures in space to account for dark regions partially devoid of stars in the Milky Way we prefer, with Dr. Barnard, to regard the appearances as due simply to irregularities of stellar distribution. Nor can we see in the tree-like forms of nebulæ sufficient reason to believe that the nebulous matter has been shot into a resisting medium. The value of these novel suggestions should not, however, be overlooked; further evidence will probably allow their true importance to be measured.

The book is completed by a table of constants of the solar system, and an excellent index. In typography and illustration the publishers have left nothing to be desired.

BOOK NOTICES.

The Visible Universe. Chapters on the Origin and Construction of the Heavens, by J. Ellard Gore, with stellar photographs and other illustrations. Publishers Crosby, Lockwood and Son, London; Macmillan & Co., New York, pp. 346.

The frontispiece to this new book is a large plate of the great nebula in Andromeda 10 inches by 6½ inches, taken from the original photograph by Isaac Roberts. This beautiful plate is a fitting introduction to one of the most useful books on general astronomy that has been published recently. It is not the object of the author to propound any new hypothesis concerning the origin or structure of the Universe, but rather to explain and discuss theories that have been supported by competent astronomers and other men of science.

The book begins with the Nebular Hypothesis and first presents the views of Kant respecting the Origin of the Universe, as they were advanced by that German philosopher in 1755. Following this and in close comparison with it are the views of the celebrated Laplace, as drawn from his work entitled *Exposition du Systeme du Monde*, published in the year 1796 and further advanced in revisions of the same work published in 1808 and in 1836, although his death occurred in the year 1827. The reader will be interested in this chapter to notice how clearly and well the author has shown the differences of the views of these two great men, who advanced theories so much alike, independently, and from such different lines of investigation. The discussion then proceeds with the views of later writers who have suggested modifications to the hypothesis, as stated by Laplace; for example, Helmholtz's idea of the Sun's heat, Newcomb, Proctor and Kirkwood's in regard to detached nebulous rings and the long periods of time claimed by the geologists. The objections to the theory as urged by Wolf in his book titled *Les Hypothesis Cosmogoniques* (1886) are presented with fairness and answered clearly and definitely on the basis of modern reasoning and scholarly research.

The second chapter deals with M. Faye's views on the Nebular Hypothesis which seem generally to accord quite nearly with those of the author. Faye's system is presented in detail, and the objections to it are named and discussed. The next step is the theme of *Stellar Evolution* which is introduced by reference to the writings of Dr. Croll, especially those published a short time before his decease, under the title, *Stellar Evolution and its Relations to Geological Time*, (*1889*). Considerable space is given to the consideration of Dr. Croll's so-called "impact" theory and how it is related to that of Laplace, on the one hand, and, on the other, to the later theory, known as the "meteoritic hypothesis" advanced by Mr. Lockyer. In this and subsequent chapters a thorough study is given to the principal points made by Dr. Croll and Professor Lockyer. The "meteoritic hypothesis," and its discussion deservedly assume large space, and the book published by Mr Lockyer under that title in 1890 is here more thoroughly and completely reviewed than has been done elsewhere so far as we know. Chapter VIII s good reading for an epitome of the "meteoritic" hypothesis within the brief pass of forty pages.

The titles of other chapters of this excellent book are, The Fuel of the Sun, The Constitution of Matter, Celestial Chemistry, The Milky Way and Star Distribution, Clustering Stars and Star Streams, Sidereal Distances and Motions, Giant and Miniature Suns, Some Earlier Theories of the Universe, Sir William Herschel's Theories, Sidereal Astronomy from Herschel to Struve, Struve's Theory, Proctor's Views, Infinite Space and a Limited Universe, and an Appendix and a General Index.

The book contains sixteen handsome plates and eleven figures, and they are, many of them new, and well devised for the purpose intended. Attention is especially called to this new book.

Sun, Moon and Stars. Astronomy for Beginners by Agnes Giberne. Preface by Rev. C. Pritchard. New and revised edition, American Tract Society, Publishers, 150 Nassau Street, New York, pp. 334. Price $1.25.

The first edition of this book was published in 1879, and to that edition Professor C. Pritchard (lately deceased), wrote a six page preface commending the book highly. He said "I have often been asked, and, which had as often puzzled me, to the effect, *Can you tell me of any little book on astronomy suited to beginners?*" (The italics belong to the preface). I think that just such a book is here presented to the reader." The reasons for the revision given by the author are, the progressive character of the science, the advancement made in every branch of it during the last decade and especially now since there is a call for an English edition of twenty thousand. Those who have seen the old edition will notice that many old passages have been omitted, and new ones interpolated, large portions of chapters have been rewritten, and that the last two are almost new ones. For the benefit of those who have not seen the edition of 1879, we give below a view in order of the contents by parts and chapters. The first part contains ten chapters as follows:

1. The Earth one of a family. 2. The head of the family. 3. What binds the family together? 4. The leading members of our family—first group. 5. Second group. 6. Our particular friend and attendant. 7. Visitors. 8. Little servants. 9. Neighboring families. 10. Our neighbor's movements.

The second part takes up the same topics as before essentially and gives more concerning each, and the third part has seven chapters with titles as follows:

1. Many Suns. 2. Some particular Suns. 3. Different kinds of Suns. 4. Groups and clusters of Suns. 5. The Milky Way. 6, Reading the light, and 7. Further thoughts.

It is not an easy task to take all these topics and write on them so simply and directly that the popular reader may find what he wants for instruction and entertainment. This author, we believe, has been successful, and we think Professor Pritchard's estimate of the work not overdrawn.

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THE YERKES TELESCOPE.

Clear Aperture of Objective, 40 inches.

Photographed by S. W. Burnham at World's Columbian Exposition.

Astronomy and Astro-Physics.

VOL. XII, No. 8. OCTOBER, 1893. WHOLE No. 118

General Astronomy.

GREAT TELESCOPES OF THE FUTURE.*

ALVAN G. CLARK.

I have been asked by the local committee, through their secretary, to prepare a paper for the Astronomical Congress, embodying my ideas on the future possibilities in the construction of great telescopes. I accepted the invitation somewhat reluctantly, for, while I appreciate the honor extended to me, I feel that the subject chosen by the committee is a somewhat delicate one to deal with, as I may say many things which do not coincide with the pre-conceived ideas of some that may be present. I beg therefore that they will regard the subject of this paper as simply the embodiment of my ideas. I shall endeavor not to state anything as a fact that has not been demonstrated as such by repeated experiments.

Much has been written and more said regarding the great telescopes of the future. It seems to me that the best method of studying the subject is by a careful consideration of what has been accomplished with the instruments already made. From my personal comparions I find that most of the important original discoveries in the truly visual line have been made with the largest telescopes in use at the time. In making this statement I would say that I do not include such discoveries as have been made from observed irregular proper motions of stars, such as, for instance, the companion to Sirius, which was known to exist some years before it was seen, although this required the largest refracting telescope then in existence to show it to the human eye. When once seen, however, with the large glass, it was readily seen with small ones. Nor would I ignore the many double stars discovered with smaller telescopes. These discoveries have been made with instruments of superior defining power, under fine atmospheric conditions, and are valuable con-

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

tributions to astronomy, yet I do not believe that a small telescope was *necessary* to make these discoveries. I am of the opinion, that had the discoverers had at their command the largest telescope, the discoveries would have been more numerous and important. When the two 15-inch telescopes were made in 1846, one for Pulkova, the other for the Harvard Observatory, they were considered monsters. I believe it was thought by most astronomers that the limit in size had been reached. No larger refracting telescope was made for a period of more than fifteen years, the next largest being an 18½-inch. I mention this fact to show how and at what time the demand for larger telescopes came. I think that the order for the 18½-inch was given in 1860. As soon as the companion to Sirius was discovered with this glass, at once there seemed to be a desire for something larger. The next larger telescope was made for R. S. Newhall of Gateshead, England. Then came the 26-inch for the U. S. Naval Observatory, and then Leander J. McCormick presented the University of Virginia with one of the same size. After that the 30-inch for the Russian Observatory was constructed, and, finally, the 36-inch for the Lick Observatory. Besides, there is now in process of construction, and well under way, a 40-inch telescope for the University of Chicago.

I have always been a believer in large telescopes for special work. I have had great experience with them, and it is from testing these instruments that I have been convinced that large instruments are needed to make original discoveries, such as new satellites to planets, and faint companions to bright stars, in fact to any stars, as well as for studying the planets and nebulæ. For astro-physical work they are vastly superior to smaller ones. The trouble that early opticians experienced in procuring good discs of glass seems to have passed away, and we are now able to procure discs of almost any size, the only obstacle being the time required to make them, and the money to pay for them.

Having given you some of my reasons for believing in large telescopes, I will now proceed with the subject of this paper, viz.: my ideas of the future possibilities in the construction of great telescopes. It is my idea that the great telescopes of the future will be refractors, not reflectors, and I shall confine myself entirely to the refractor. I would not wish to say anything that might lead you to suppose that I underestimate the value of the great discoveries made with reflecting telescopes, or the great minds that have made and worked with them, yet one person of eminence did remark that *large* reflecting telescopes have never accomplished much except in the hands of the opticians who made them; and my own experience has been sufficient to convince me that the reflector is extremely sensitive to any changes either of temperature, or air currents, or more particularly to flexure, and that while the refractor is also affected by these changes, it is by no means so injurious to the definition.

As I have said, I believe that good discs of any size, both crown and flint, may now be procured. Having once procured them, all that is required is an optician to work them. He must be an artist in light and shade, and in color also, for the very best correction of the chromatic aberration. As in the light and shade we search for and locate the spherical aberration, so we work among the different colors for the chromatic corrections. It is a very difficult task, and as the size is constantly being increased, the difficulties also increase. Personally I do not believe this work can ever be accomplished by machinery. Not that machinery might not be made available for the rough work and the first polishing, for we ourselves polish all our large surfaces in a machine in a preliminary way. The fine grinding and smoothing, however, is always done by hand. It is after the first machine-polishing is done, and the glass appears to be finished, that what I have referred to as artistic work begins; that is, the work to locate the errors from observations, and correct the surfaces of the glass by the tentative method till all the light from a point at an infinite distance will be refracted to a point at the focus of the objective so accurately that the image there formed will bear the highest magnifying powers without showing any distortion. I believe that this can be accomplished only by most careful study of the light that has passed through the objective, and that all the errors must be worked out by what is termed local corrections.

When the time is ready, I think the man capable of making the necessary observations and locating the errors with precision, as well as skillful enough to work them out on much larger objectives than have yet been attempted, will be found. The simple preliminary grinding and polishing of large lenses is not a very difficult operation; this, with the centering is purely mechanical. But if the glass itself has the slightest uneveness in its density, be it ever so small, the refraction will be different through the different densities. This cannot be determined with certainty until the discs have been worked into an object-glass, or at least, ground and polished for that purpose. If, after this grinding and polishing has been done with the greatest eare, we find the image produced by the lens which is achromatic is not symmetrical, and that a star at the focus is not round, but possibly is elliptical, rectangular, or in fact of any shape, what is to be done? After so much expense and labor, shall we condemn the glass, and wait perhaps years for other discs, which, after going through the same process, may give no better result? I will state here that of all the large glasses, that is to say over 18½ inches aperture, that have been made by Alvan Clark & Sons, only one, viz.: the Princeton 23-inch, came from the polishing machine giving a perfectly round image. All the others we had to round by local work.

I believe the optician that is to make the large telescopes of the future, as well as the present, must be able to do this work. In my opinion it is not more difficult than the correction of the spherical aberration proper, though if much out, it may prove more laborious. Surely I believe this work should be done rather than condemn the discs and try others. Each glass can be rounded separately. For this purpose set the combined lens in front of a collimating mirror. An artificial star is produced from a lamp by reflecting the light from a minute lens within the eye-tube, and close to the optical axis and focus of the objective. The light from this artificial star passes through the tube to and through the object-glass, then on to the collimating mirror which should be as flat as possible. From the mirror the light returns to all portions of the objective in parallel rays. There must, however, be a little off-set so that the returning light from the star will not fall on the minute lens where the star was first formed, but the deviation from the true optical axis is but a mere trifle. Of course it would be almost impossible to secure perfect definition under these circumstances with a very large glass, as the combined errors or imperfections are made to appear twice as great as they really are, from the fact that the light has passed both ways through the objective, so that the imperfections in the material, that is the glass itself, and workmanship also, are made to appear double what they will be when used as a telescope for viewing celestial objects direct. Nor is this all, for we have the imperfections of the mirror to contend with, and who can conceive of a mirror of five or six feet in diameter resting on its edge, being perfectly symmetrical. You may think it strange if I say that while I should much prefer to have everything perfectly correct for this work, I believe it impossible, and we must do the best we can under the existing circumstances. I remember a time when a distinguished professor was shown by my father, our apparatus and methods of testing lenses. The professor asked, which are you testing, the mirror or the objective? My father's reply was, we are testing both, and surely we can test both by the method used.

After observing all the appearances in one position, the next thing to be done is to give the whole or combined glass, that is the crown and flint together, a partial turn. If appearances are changed, it is certain there is some error in the objective, for if the glass worked perfectly, no matter what imperfections were in the mirror, they would be the same which ever way you turn the objective. Having ascertained that the combined glass is not round, or rather does not give a round image of a star a little out of focus, the next thing is to locate the error or errors. Are they in the crown or flint lens? Probably in both. This is, however, ascertained by first revolving one glass. If an irregularity is detected that rotates with the glass, it must be corrected by skillfully working the surfaces, so that the portions that are of short focus shall be lengthened and those of long focus shortened until the rays shall come together at the general focus. After having rounded this lens so that no apparent change is visible by rotation, this glass must remain fixed, and the other must be examined and worked in the same manner. This work having been carefully carried out on both crown and flint lens, they are surely round, though they may not give a round image from the mirror. After the glass is rounded, the mirror itself may be corrected in the same way, but this is not absolutely necessary as we already know the errors. This rounding of a large glass is very laborious, and sometimes requires months to accomplish. Yet the party that is to make great telescopes in the future, as well as the present, should in my opinion make himself familiar with all these tests, and have the ability to work out the errors that I have described, together with those that may arise from concentric rings of different foci.

Having stated my ideas as to the necessary requirements to make large telescopes, I will now call your attention to my idea of the great telescope itself. As before stated I am of the opinion that it will be a refractor, and that its size will progressively increase. It will be mounted equatorially, and provided with the best driving clock that can be devised. I am in favor of the long polar axis, known as the English plan, for such an instrument, my reasons being, first, that a large driving wheel may be applied without setting the telescope to one side of the axis. The polar axis itself may also be braced in any or all directions, without [illegible] this axis can be made [illegible] can be braced to [illegible] be easily provided [illegible] required. To make [illegible] one for visual and [illegible] conditions as to [illegible] little or no extra [illegible] would be [illegible] generally ad- [illegible]

[illegible] these instruments. I [illegible] on the locali- [illegible] the best [illegible] preliminary [illegible] it ordi- [illegible] conditions. A [illegible] circumstances, [illegible] under the very best con- [illegible] our present [illegible] this will [illegible] knowledge. The [illegible] [illegible] or [illegible] broadened [illegible] I see the [illegible] interpretation, and [illegible] interpreters.

THE ORBIT OF [illegible]

[illegible]

The pair (Σ [illegible]) has long been recognized as a binary system but hitherto no orbit has been attempted. For the half century following the first measures by Struve, the change in the components was substantially all in the distance which has been steadily diminishing during the whole time. For many years past it has been a very difficult pair, and has often been noted as single. An inspection of the measures shows that until recently the two stars must have been separated by what would be a measurable distance in the largest refractors, though in

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* Communicated by the author.

some of the smaller instruments the elongation would be difficult to detect.

The last measure of this pair was made by me at Mt. Hamilton in 1890, with the 36-inch refractor. The distance at that time certainly did not exceed 0″.1. After these measures were made, Mr. Gore computed the orbit (A. N. 3129) and found a period of 117.54 years. As all the measures between 1831 and 1890, had put the smaller star in the second quadrant, this orbit necessarily depended upon my position in 1890, where the companion was placed in the fourth quadrant. I examined this pair on one night in 1889, with the 36-inch, and noted it as single. In the following year I observed it on two nights, and obtained fairly good measures of the angle, the distance being estimated at 0″.1 or less. It was obvious that if an occultation had taken place, the companion could no longer be in the second quadrant, and therefore the angle was given in my observations as 347°.0. A difference in the components of, a little more than one magnitude would not be apparent in so close a pair. In the following year (1891) I expected the distance would be increased so that it could be measured without difficulty, but when it was examined under very favorable circumstances with the 36-inch, I found that it was practically single (A. N. 3114). There was no certain elongation on three first-class nights. It follows, therefore, that the position angle in 1890, should have been 167°.0, and not 347°.0 as I have given it in my measures (A. N. 3048). Mr. Gore was doubtless misled by my observations in 1889 and 1890, and assumed, as I did, that the companion had passed around to the opposite quadrant, giving a total angular motion of at least 230° in the sixty years covered by the measures. This would have been sufficient for the determination of a good approximate orbit. It is very probable that my failure in 1889, when the distance could not have been much more than 0″.1, to notice any elongation, and hence calling it single, was a mistake, since it was very carefully observed in 1891; and therefore until the companion reappears no investigation of the relative motion can be made. It is impossible to predict the time when this will probably occur, or whether it will be in the third, fourth or first quadrant. Down to this time the motion is practically rectilinear, and the apparent ellipse, so far as appears, may be either exceedingly eccentric, or the projection of a circular orbit, lying nearly in the line of sight.

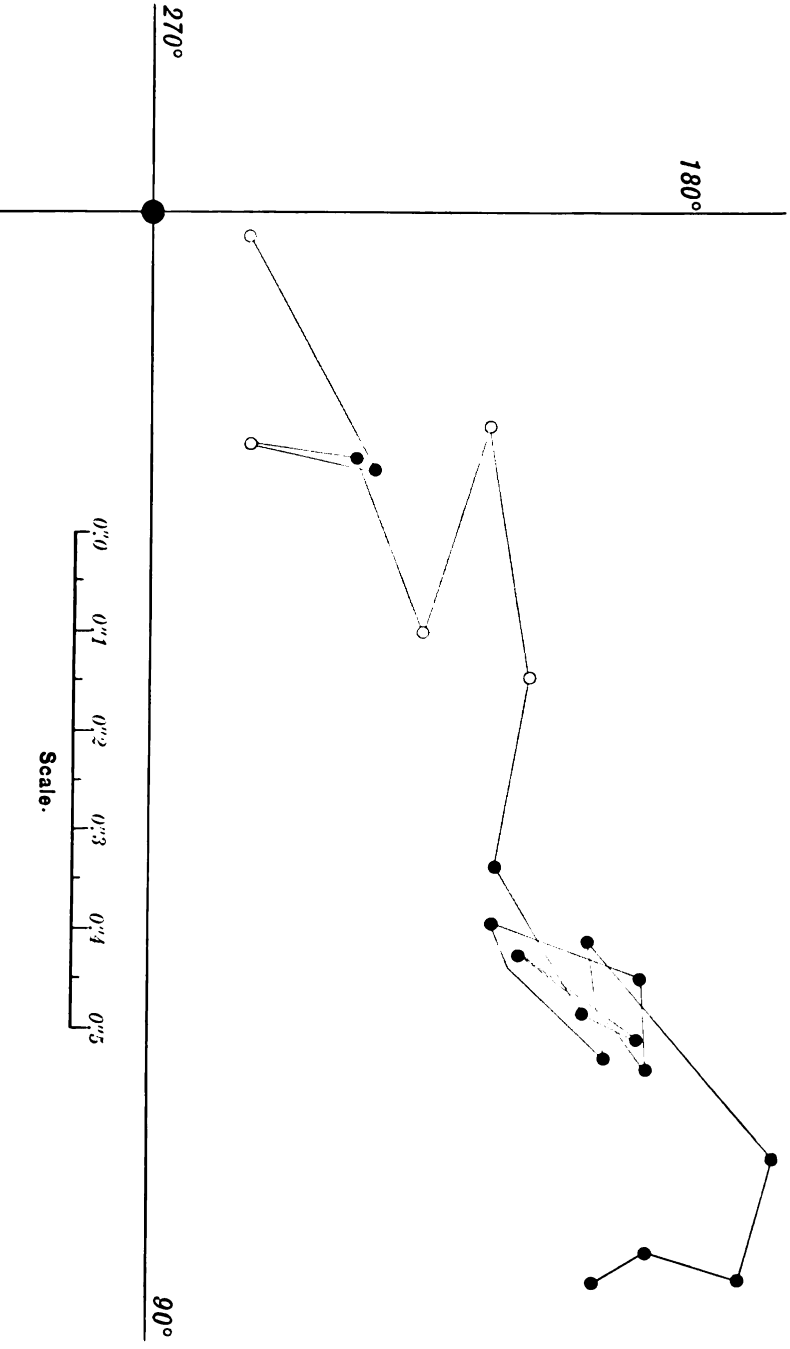
The following are the observations of this pair:

1830-31	132°.2?	1″±	1n	J. Herschel
31.12*	112 6.	1.16	3n	Struve
35.67*	115 .6	1.15	2n	Struve
39.69	119 .0	1.22	1n	Dawes
41.64	106 .2	0.65	2n	Madler
.65*	123 .5	1.13	1n	O. Struve
.88	118 .1	......	2n	Dawes
42.80*	121 .1	0.85	3n	Madler
43.65*	120 .1	0.82	2n	Madler
.85*	116 .7	1.11	2n	Dawes
45.51*	115 .8	0.79	1n	Madler
47.57*	121 .8	0.97	1n	Mitchell
.98*	123 .9	0.85	1n	Madler
51.85*	126 .2	0.67	2-1n	Madler
.89*	114 .4	1.31	1n	W. Struve
52.67*	116 .4	0.83	1n	O. Struve
53.88*	118 .7	1.11	1n	Dawes
.94*	122 .8	0.81	1n	Madler
54.74*	118 .5	0.91	3n	Dawes
.78	114 .2	......	1n	Madler
55.82	118 .4	......	1n	Madler
56.78	127 .7	0.6±	1n	Madler
57.09*	117 .9	0.74	4n	Secchi
.87	116 .3	0.7±	2n	Jacob
58.00	128 .2	......	2n	Madler
59.87*	129 .3	0.6±	1n	Madler
60.69	119 .8	......	1n	Dawes
1861.98*	148 .0	0.4±	2n	Madler
63.66	113 .2	......	3n	Dembowski
66.71	99 .1	0.5±	2n	Winlock
.67	96 .6	0.5±	1n	Searle
.69	132 .9	......	1n	Searle
.76	116 .4	......	1n	Searle
67.65	111 .8	oval	1n	Dembowski
68.76	138	......	1n	C. S. Pierce
69.67	132 .0	......	1n	C. S. Pierce
.75	114 .8	......	1n	C. S. Pierce
71.92	122 .3	0.5±	1n	Wilson & S.
72.56	116 .7	obl.	1n	Dembowski
73.78*	119 .3	0.5±	1n	Wilson & S.
.87*	119 .6	0.5±	1n	Gledhill
.88*	130 .6	oval	1n	Dembowski
75-77	......	invisible	...	Doberck
77.75	118 .8	0.3?	1n	Dembowski
78.63*	130 .0	0.32	1n	Burnham
79.57*	113 .4	0.25±	1n	Burnham
.86	128 .3	......	1n	Seabroke
80.59	......	single	1n	Burnham
85.53*	131 .4	0.34	5n	Engelmann
.72	......	single	2n	Perrotin
89.59	......	single ?	1n	Burnham
90.56*	167 .0	0.1±	2n	Burnham
91.64	......	single	3n	Burnham

Leavenworth has a measure made in 1886 (*Publications of the McCormick Observatory*, Vol. I, Part 4) which is credited to this pair, but it obviously belongs to β 291, a close pair in the immediate vicinity of 37 Pegasi.

The relative change in the components will be seen from the accompanying diagram on which the the principal measures are

PLATE XXXVI.



37 Pegasi.

laid down to scale. These measures are marked with a (*) in the preceeding list. When two or more observations, made in the same year, are used, a simple mean is taken.

The tendency of the observed positions to arrange themselves in groups, which, as I have heretofore shown, is always found in stars of this class where the relative motion is small compared with the errors of observation, is well marked in this instance.

THE DOUBLE STAR, 95 CETI (A. C. 2).*

S. W. BURNHAM.

This star was discovered to be double by the great optician, Alvan Clark, on December 20, 1853, with one of his own objectives of 7½-inches aperture. He sent this, with other newly discovered stars, to Dawes, and in the following year that observer measured the position-angle on three nights. He found it very difficult to measure, and estimated the distance from 0″.7 to 0″.8, the small star being rated as tenth magnitude. Unfortunately, from this time on Dawes paid no further attention to it, and it was wholly neglected or forgotten for nearly a quarter of a century by all other observers. I do not know of a single reference to this pair from the time of Dawes' observations in 1854, until the publication in 1882 of my measures with the Dearborn telescope made in 1878. In this interval, however, it seems to have been looked for at the Harvard College Observatory as appears from some double star observations published about ten years ago. These will be referred to hereafter.

The following are the observations of this pair negative and otherwise:

1854.81	73°.1	0″.7 ±	3n	Dawes
1878.85	......	Single 18½-in.	2n	Burnham
1886.74	......	Single 26-in.	2n	Leavenworth
1888.77	112°.8	0.45	2n	Burnham
1890.87	......	Single 36-in.	2n	Burnham
1891.73	......	Single 36 in.	1n	Burnham

I had examined this pair many times prior to 1878, commencing with the 6-inch refractor about 1870. In fact, I must have looked at it altogether hundreds of times with various instruments, but until 1888, never could see the least trace of the companion. It began to seem probable that there was some mistake in the identity of the star, or otherwise, as it appeared

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* Communicated by the author.

improbable that the companion in a star of this class, should so long remain invisible. When it was examined at Mt. Hamilton in 1888 with the 12-inch refractor, it was seen and measured with that instrument, the companion being called eighth magnitude. The second measure was made with the 36-inch, and the companion rated ninth magnitude. In 1889, in consequence of my absence on the eclipse expedition, I failed to observe it. In 1890, it was carefully examined on two good nights with the 36-inch, but the companion was invisible. In 1891, on a remarkably fine night, the same instrument with powers up to 1900 failed to show any trace of the companion or elongation of the principal star.

The observations at the Harvard College Observatory, previously referred to, are as follows:

1866.88	12°.9	—	1n	Searle
.88	350 .9	—	1n	Winlock
66.90	26 .7	—	1n	Winlock
67.09	82 .6	—	1n	Winlock

Evidently in at least three of these observations, the companion was not seen at all, and there is nothing to do but reject them all. It will be seen that Winlock's angles differ from each other by more than 90°, and Searle's position does not correspond with either of the others. It is incredible that these observers should have allowed the matter to rest here, without taking the trouble to ascertain which one of the four measures, if either, was entitled to any credit. In the last observation, the seeing was described as "magnificent," but the discordant measures were allowed to stand, and no verification attempted subsequently, and as the first two have nothing to indicate that they were not made under proper atmospheric conditions, there is no justification for selecting any one of these observations, and throwing the other three away.

It is certain that we have in 95 Ceti, a most remarkable binary system. The principal star has a proper motion of 0″.242 in the direction of 104°.8. It is impossible from the two measures we have to say anything about the relative motion. It may be very rapid. The observations of 1888 and 1890 would appear to indicate this. It is possible that the companion has made two or more revolutions since its discovery. At the same time, the failures to see the companion during the fifteen years preceding 1888, rather point to slow change. These doubts will be settled by keeping watch of this star each year, and getting a measure as soon as the companion is again visible. This may be seen any year, and it is important that it should be carefully looked for.

In this connection it may be mentioned that while examining this star in 1890 with the 36-inch, I found a new pair in the field which may prove to be an interesting system. This is a 9m star $31^{s}.7$ following, and 5′ 42′′ south of 95 Ceti. The components are equal, the distance being about 0″.4 (β 1177).

CHICAGO, Aug. 8.

A FIELD FOR WOMAN'S WORK IN ASTRONOMY.[*]

MRS. M. FLEMING.

In the earliest records of ancient Greek History we can trace the great interest which centres in the heavenly bodies, and in Astronomy, the greatest of all sciences, but in no way do we find women connected with the study of this science until a comparatively recent date. Caroline Herschel, Mary Somerville and Maria Mitchell were, as women, pioneers in this work. We cannot say these were the only women of their time capable of devoting themselves successfully to this work and of adding to our knowledge of the heavenly bodies and of the laws which govern them. Caroline Herschel and Maria Mitchell had rare opportunities afforded them, the former in that she had a brother who was thoroughly devoted to the work. Probably through him her interest was aroused and she became his assistant and his untiring companion in his researches. Maria Mitchell, in all likelihood, acquired a similar interest in Astronomy from her father, and her high standing as an astronomer is acknowledged by all connected with the study of this science. A great many women of to-day must have a similar aptitude and taste for Astronomy and if granted similar opportunities would undoubtedly devote themselves to the work with the same untiring zeal, and thus greatly increase our knowledge of the constitution and distribution of the stars.

The United States of America is a large country, with a large-hearted and liberal-minded people. Here they have made room for comers from all other countries, have welcomed them and have given them a fair open field and equal advantages in pursuing their labors or studies, as the case may be. There is no other country in the world in which women, not as individuals, but as a class, have advanced so rapidly as in America, and there is no

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[*] Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

other country in which they enjoy the same unlimited freedom of action which affords them the opportunity to find their own level. In their studies they encounter very little narrow-mindedness or jealousy in their brother students or fellow workers in the same field of research, but in general they are treated with the greatest courtesy, encouragement and assistance being graciously accorded. Women, therefore, who have taken up any branch of science, or indeed work of any kind, need not be discouraged in it even if one or two of the great mass which goes to make up the whole in their superior judgment refuse to give credit to their work. Labor honestly, conscientiously and steadily, and recognition and success must crown your efforts in the end.

Photography, as applied to Astronomy is one of the greatest advances which has been made in this the oldest of sciences, and this same advance has opened up a comparatively extensive field for woman's work in this department. Dr. Henry Draper of New York was the first scientist who photographed successfully the lines in a stellar spectrum. His wife, Mrs. Anna Palmer Draper, was his constant companion and assistant in all his experiments and researches. On the interruption of his valuable investigations by his sudden death in 1882, Mrs. Draper, knowing the great value of the work already done, decided that the investigations should be continued at the Harvard College Observatory under the direction of Professor Edward C. Pickering, and she set aside a liberal sum of money to be used for this work, thus founding the department known as "The Henry Draper Memorial." In 1886 there were three women computers engaged in the work in this department; at the present day there are twelve women engaged in the same or in similar work. Miss Catherine W. Bruce of New York has shown her appreciation of the photographic work now being carried on at the Harvard College Observatory by her generous gift to that institution of $50,000 for the erection of a photographic telescope of the largest size. The Observatoy has a corps of about forty assistants, seventeen of whom are women, and twelve, as stated above, are engaged, more or less, on the photographic work.

The photographs obtained with the various telescopes now in use at the Harvard College Observatory in Cambridge, and at the auxiliary station near Arequipa, Peru, are of various classes, the most important of these being chart plates having exposures of from ten to sixty minutes or more, spectrum plates having exposures of from ten to sixty minutes, and trail plates having several exposures of a few seconds duration. The women assistants are not engaged during the night in taking these photographs but find their time during the day sufficiently occupied in examining, measuring, and discussing them, and in the varions computations therein involved. Catalogues, for reference, of the plates taken with each instrument have to be kept up to date, the plates have to be compared with the charts of the part of the sky which they are supposed to represent, in order to check the correctness of the record made by the observer, and to ascertain that the region intended is contained on the plate. The chart plates are then filed carefully away and are used in the confirmation of variable stars or other interesting researches. The most important work at present being done from the chart plates taken with the 8-inch Draper telescope in Cambridge, and with the 8-inch Bache telescope in Peru, is the measurement of the faint stars for stand ards of stellar magnitudes. These measurements of about forty thousand stars are now being made by Miss Eva F. Leland. She is also engaged in the measurements of the brightness of the stars in clusters. Miss Louisa D. Wells and Miss Mabel C. Stevens have shown great skill and accuracy in making the identification of stars shown in the photographs, with those contained in existing catalogues. The photographs of stellar spectra are all carefully examined in order to detect new objects of interest, such as third type stars, fourth type stars, fifth type stars or those, whose spectra consist mainly of bright lines, and similar to those discovered in Cygnus by Wolf and Rayet, planetary nebulæ, and variable stars. All of these except the first named class differ so much from the general mass of stellar spectra, that a trained eye has little difficulty in detecting them on the photographic plates, even although the objects found are sometimes as faint as the ninth magnitude. If an object is detected on any of the photographs showing a spectrum of the third type, having also the hydrogen lines bright, it is at once suspected of variability, since only variables of long period are known to possess this peculiarity. The catalogues of the plates taken with the different instruments are then consulted, and a list is made of all the plates covering the region of the star suspected of variability. So you have, ready to your hand and for immediate use, the material for which a visual observer might have to wait for years and certainly for months. This material must also be considered more reliable, for in the case of a visual observer, you have simply his statement of how the object appeared at a given time as seen by him alone, while here you have a photograph in which every star speaks for itself, and which can at any time, now or in the years to come, be compared with any other photograghs of the same part of the sky.

Many interesting discoveries have been made from the study of these photographs of stellar spectra. First in importance among them, was the discovery that ζ Ursæ Majoris is a close binary star, the two components revolving around each other at a velocity of about a hundred miles a second, in a period of about fifty-two days. This discovery was made by Professor Edward C. Pickering, his attention being first attracted to it by the fact that in the photographs of the spectrum of this star, the lines appear sometimes double and at other times single. This discovery led to the finding of a second object of this same class, β Aurigæ, by Miss Antonia C. Maury. This last star has attracted public attention much more widely than ζ Ursæ Majoris and may be considered more interesting in that the period of revolution of the two components is only 3 days 23 hours and 36.7 minutes. ζ Ursæ Majoris and β Aurigæ are such close double stars that they could not possibly be separated visually with the most powerful instruments at present in use. A third object of this class is suspected in β Lyræ which shows a similar change, or rather it shows a reversal in the position of the bright lines with regard to the dark lines in its photographic spectrum, that is, they apparently cross and re-cross each other. This is doubtless associated with the variation in the light of this star since the period is the same for both. The examination of the photographs of the brighter stars has been made by Miss Maury who has also been engaged on their classification. The micrometric measurements of the lines in the photographic spectra of the bright stars have been made by Miss Florence Cushman.

From the examination of the photographs of stellar spectra, thirty-eight stars having spectra of the fifth type have been added to the sixteen previously known, making the known number in all fifty-four. Three of the stars in this list have been discovered during the past few days and have not as yet been announced elsewhere. Twenty-three new variable stars have been discovered in this same examination of the photographs, and before being published each and all were confirmed by Professor Pickering. Two of the twenty-three have not yet been announced elsewhere since one of them was discovered only yesterday. This star is in the wonderful southern cluster ω Centauri, the finest in the sky, and being so situated would probably never have been discovered by other means than photography.

The other star is in Columba and is the first variable discovered in that constellation. Its position for 1875 is in R. A. 5^h 45^m $41^s.9$, Dec. — 29° 13′.7.

One must not always cling to the earliest method of accomplishing anything and assume that because it was the earliest and has held sway for centuries, it must consequently be the best, and also the only way. Where should we be to-day if we did not advance steadily in all things? Taking light for instance, first we have rude torches and rush lights, then candles by which the day was measured off into hours, this followed by lamp light, later by gas light, till now we have electricity to light our streets and our dwellings. And powerful as electricity is in itself for all purposes to which it has been applied, who among us can say that in it we have attained the highest degree of perfection in illumination? So it is with everything else we may take up, and so it is with astronomy. And thus while the old time astronomer clings tenaciously to his telescope for visual observations, astronomical photography is leaving him far behind and almost out of the field in many investigations which nevertheless he still continues in his own way, trying also to maintain that, as stated above, it must be the best, if not the only way. If photographic work is to be entirely ignored by the astronomers of the old school as they may be called, because, as they themselves say, they have no knowledge of photography, and not having the means at their command, do not wish to acquire a knowledge of it, what is to become of the researches planned and undertaken by the Astro-Photographic Congress of Paris, in which astronomers of all countries have united? We may safely say that the younger, more advance guard of civilization will uphold photography and encourage it as applied to astronomy, as in other scientific researches in which it is also successfully employed.

A new variable star in the constellation Delphinus was discovered from the photographs some time ago, and was announced in "The Sidereal Messenger," Vol. X, p. 106. Two skilled visual observers undertook to observe it in order to confirm, or refute, its variability. One arrived at the conclusion that it was not variable and was always about the ninth magnitude, while the other also found that the star was not variable, but according to his observations it was always about the eleventh magnitude. When they met together to discuss this difference in magnitude, they discovered that each had been observing a different star, and further, that neither of them had observed the variable. No such error could have occurred from the comparison of the photographic charts.

Unlike telescopic observations, the photographs are available always, at any time during the day or night, for consultation and examination. Therefore, while an observer with a telescope, be it even the most powerful that can be made, is at the mercy and dependent upon the state of the weather for his observations, the discussion of the photographs goes on uninterrupted and is undoubtedly much more reliable than visual work, since when a question of error in observation arises, anyone interested in the research can, at any time, revise the original observation by another and independent examination of the photograph.

Given the instruments, and materials required, with a knowledge of how the instrument is used, you can obtain in one night what would represent years of hard labor in visual observation, and in the necessary computation involved in reducing and charting these same observations. Even when finished the visual observer's chart may be subject to various errors in the positions or in the brightness of the stars with which he has dealt, but the photograph cannot fail to be an exact and unquestionable record which can be consulted and compared with others years hence, and thus serve to prove or disprove variations in light, changes in position, and in the case of the spectrum plates, changes, if any, in the constitution of the stars. Thus on a photographic plate, on which it has taken only a few minutes to reproduce the portion of the sky covered, you have a true chart of the stars in that part of the sky at that time, the limiting magnitude being dependent on the duration of the exposure and also on the sensitiveness of the plate used.

In a catalogue of variable stars recently published and entitled "Second Catalogue of Variable Stars," a more correct title would be "Second Catalogue of Variable Stars discovered Visually," since in it no weight is given to photographic observations further than is necessary to enable them to swell the list of stars discovered visually. Stars discovered photographically which have been announced as variables, and have been proved beyond doubt to be variables, are here credited as "suspected."

In conclusion, while I may be thought to have strayed far afield from the subject on which I was supposed to address you here, the investigations and researches described above are those in which the women in this department are engaged, in which they are thoroughly interested, and in which they are becoming trained and competent assistants.

While we cannot maintain that in everything woman is man's equal, yet in many things her patience, perseverance and method make her his superior. Therefore, let us hope that in astronomy, which now affords a large field for woman's work and skill, she may, as has been the case in several other sciences, at least prove herself his equal.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., August 4, 1893.

ω CENTAURI.*

SOLON I. BAILEY.

The cluster ω Centauri lies just within the northern border of the Milky Way at R. A. 13^h 19^m 16^s; Dec. — 46° 49′.5 (1875, Gould).

All the stars within a radius of 5° are of the sixth magnitude or fainter. To the naked eye the cluster appears as a hazy star of less than the fourth magnitude. In a field-glass, it becomes a globular mass of nebulous light, dense at the centre, and gently fading away at the border. The globular form is in general very perfect, but to the north it appears slightly flattened. With a telescope of high power it becomes a maze of faint stars, well defined and separated, but projected, toward the center of the cluster, upon a background of faint nebulous light. Some interesting photographs of this cluster have been made recently with the Boyden telescope of 13-in. aperture and 16 feet focal length. A brief study has been made of the number and distribution of the stars composing this group as shown on one of these photographs. The plate was made May 19, 1893, and the exposure was two hours. The 8-in. finder, which had been previously used for purposes of following, was found after many trials to be incapable of giving sufficiently exact results for this work, and an eyepiece was inserted into the field of the main telescope itself. By this means the photographic images were greatly improved. The precise limits of the cluster are hard to define, but for the purposes of this study a region 30′ square was taken, having for its centre the centre of the cluster. As may be seen from the diagram giving the enumeration, the cluster fills this region fairly well and perhaps extends a little beyond. Within this region is no star so bright as the eight magnitude. A field-glass of good power shows no individual star. Within this region Dr. Gould in his

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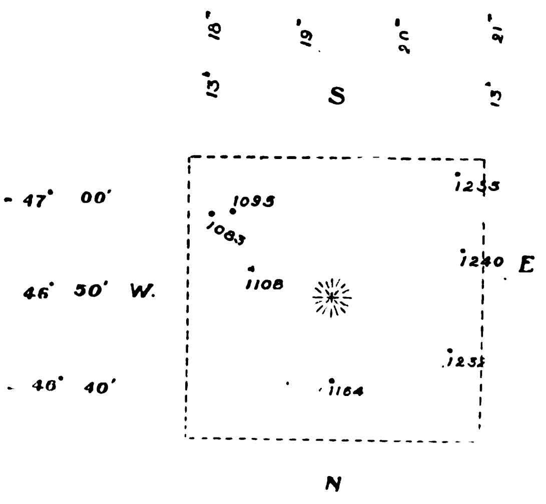
* Communicated by Edward C. Pickering Director of the Harvard College Observatory.

"Zones" gives seven stars: 13 h. 1083, 1095, 1108, 1164, 1232, 1235 and 1240. The magnitudes given are respectively 8½, 8½, 9, 8½, 9, 9, 9. The position of these stars in respect to the centre of the clustre is shown in diagram 1. They are found on the photograph in squares Ea, Eb, Id, Pk, Ms, As, and Gs. (Diagram 2). They include all the brighter stars of the cluster. The magnitudes now correspond fairly well with those given above, with the exception of 1095. My estimates of the visual magnitudes are 8.7, 9.5, 8.8, 8.5, 9, 8.8, 9.2. In the zones, 1095 is given equal in brightness to the close star 1083. It is now nearly a magnitude fainter and may be a variable. Photographically, 1108 is about the same brightness as 1164 and 1235 is brighter than 1083.

Diagram 1.



For the purpose of the count, a series of black lines were drawn on white paper, one centimetre apart. Four hundred squares were thus formed. This was then photographically reduced on glass and a glass print made giving a transparent field with fine dark lines. The size of this reticule was 4.4 c. m., and its scale was such that the region covered was 30′ square, each little square having for its side 90″ of arc.

This reticule was placed over the negative, the whole placed in a frame having proper illumination and the number of stars in each square counted. A compound microscope, with a magnifying power of 40 diameters, was used. The cross-hairs of the eyepiece divided each square into four sub-squares, which served to prevent confusion in counting. By estimate the photographic stellar images, except in the case of a few of the brighter stars, differed very little from 4″ in diameter. With the magnifying power used, the images had a slightly elliptical form, which, however, proved an advantage as it enabled the star images to be distinguished from any possible imperfections in the plate.

DIAGRAM 2.

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		63	78	110	146	201	280	335	470	637	681	672	632	506	476	336	253	185	141	104	83	6389	
	A	2	2	2	4	3	1	4	4	6	3	2	3	6	3	7	5	6	6	3	3	75	
	B	2	4	5	3	4	4	4	4	4	3	6	5	6	5	10	6	7	3	4	3	92	
	C	2	2	4	7	10	8	4	8	4	9	8	10	8	10	7	6	5	10	4	2	128	
	D	2	0	2	6	5	4	7	6	10	10	12	14	6	12	4	10	6	4	4	8	132	
	E	4	2	6	6	10	6	9	10	10	18	26	18	11	19	7	7	12	6	4	6	197	
	F	3	2	5	6	6	14	14	19	19	22	23	24	26	25	11	12	3	5	5	4	248	
	G	5	6	8	6	9	12	25	26	34	47	34	44	32	38	16	12	13	8	10	7	392	
	H	5	6	6	16	10	20	26	30	52	54	58	59	44	46	27	26	14	14	7	4	524	
	I	6	8	8	10	21	28	37	60	75	81	66	74	62	58	44	20	10	9	4	8	689	
W	J	3	4	7	12	14	31	46	65	89	91	98	92	71	62	42	24	10	6	6	4	777	E
	K	4	6	13	18	21	34	40	62	88	100	96	80	60	54	35	27	16	15	6	6	781	
	L	2	10	5	9	14	38	33	52	77	74	83	68	48	42	44	27	25	6	8	8	673	
	M	2	6	5	13	13	26	26	40	62	71	62	58	38	32	24	16	16	14	10	4	538	
	N	6	3	10	10	18	22	18	28	38	32	29	29	32	20	8	16	10	12	6	1	348	
	O	3	5	4	4	10	12	12	18	30	28	21	20	18	14	12	12	8	6	4	8	249	
	P	3	6	4	4	5	4	5	16	10	18	14	10	12	9	12	7	8	4	4	1	156	
	Q	4	1	8	6	6	4	8	9	12	6	12	10	10	6	12	8	5	5	6	2	140	
	R	0	2	4	1	8	7	9	8	9	6	10	8	8	8	6	10	4	5	4	2	119	
	S	4	1	3	3	10	4	2	3	5	6	4	2	2	3	4	0	1	3	2	2	64	
	T	1	2	1	2	4	1	6	2	3	2	8	4	6	10	4	2	6	0	3	0	67	
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	6389	

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All objects not of this form were rejected. Toward the center of the cluster, counting was somewhat difficult but doubtful objects were discarded. The numbers given do not represent the full number of stars that left their impression on the plate. Toward the center of the cluster, the background between the distinct images was of a faintly mottled gray, apparently due to stars too faint and closely packed to make distinct records. No account was made of this background except where it became sufficiently differentiated to assume the peculiar form referred to above.

Near the center of the cluster, chiefly in square Jj, occurs a peculiar break in the brighter stars. The number is preserved, however, since there is a background of fainter stars.

Diagram 2 shows the number of stars counted in each square. The sums at the side and top show in a general way the condensation toward the center. The cluster was counted independently, twice, once by Mrs. Bailey and once by myself. The results obtained were 6402 and 6373 stars respectively. The disagreement arose from the fainter mottled background, as the negative showed every gradation from a nearly even shading to a decided mottling. This appearance seems to be due to close faint stars rather than to nebulous matter. The numbers given in the squares are the means of the two counts, and the sum of the means, 6389 stars, may be safely assumed to be the approximate number of stars that made distinct impressions on this plate.

There can be no doubt, however, that the whole number of stars comprising this splendid cluster is very much greater.

AREQUIPA, Peru.
June 30, 1893.

POLAR INVERSION OF THE PLANETS AND SATELLITES.*

WILLIAM H. PICKERING. †

By the term Polar Inversion is meant the gradual turning over of a planet, so that its north pole occupies the position formerly held by its south and *vice versa*. In ASTRONOMY AND ASTRO-PHYSICS for June the inversion of the poles of the directly rotating planets and satellites of the solar system was ascribed to the action of the tides set up in them by their primaries. This action appears to be sufficient to explain the inversion in the case of the satellites, and in general of any body whose period of rotation upon its axis is not less than its period of revolution around its primary. It does not, however, fully explain the case of rapidly rotating bodies like the planets, since in their case the inversion could not proceed much further than to make the axis coincide with the plane of the orbit. A second cause of inversion has recently been found which in its action is probably still more important than that of the tides.

Let us first imagine a wheel *AB*, whose axis coincides with the plane of its orbit about its primary *C*. The part *B* will be attracted more than the center of gravity of the wheel, and the part *A* will be attracted less. The tendency will therefore be to cause the wheel to turn so that its plane *AB* shall pass through *C*. If the attraction is sufficiently powerful, or is continued indefinitely, this position will be maintained in all parts of its orbit, as shown at *DE* and *FG*. If, however, the wheel begins to rotate upon its axis, a new series of forces will come into play. The

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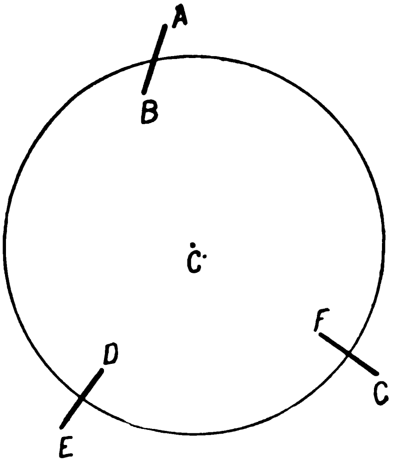
* Communicated by the author. † Harvard College Observatory.

effect of the rotation will be to cause the wheel to endeavor to retain its original plane in spite of the attraction of the central body. Nevertheless this attraction will produce a certain effect setting up a very slow rotation of the plane of the wheel about an axis perpendicular to the plane of its orbit. If the plane of the wheel had been inclined to the plane of the orbit, instead of perpendicular to it, the same effect would have been produced, only the rotation of the plane would have been in this case still slower.



Let us now take any rotating body, revolving in a retrograde direction, and change the plane of its rotation by a direct rotation perpendicular or inclined to the primary axial rotation. The result will be that the body, if left free to itself, will slowly invert its poles, and take up a plane of rotation parallel and in the same direction as the disturbing rotation. This action of rotating bodies is a well known principle. For a convenient mathematical demonstration of it see Johnson's Encyclopedia, article Gyroscope, by Professor J. G. Barnard.

We may therefore say that since such a disturbing rotation necessarily occurs in all the planets and satellites of the solar system that the poles of such of them as have like Neptune and Uranus a retrograde rotation, must in process of time be inverted, and that in the end all of them will sooner or later assume planes of rotation parallel with the planes of their orbits.

HARVARD COLLEGE OBSERVATORY,
Sept. 6, 1893.

ON THE FORM OF THE CORONA APRIL 16, 1893.

J. M. SCHAEBERLE.

With reference to the form of the corona April 16, the hasty and unguarded remarks attributed to Messrs. Pickering, Fowler

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* Communicated by the author.

and Taylor in the August number of *The Observatory* are not, according to my view, in agreement with the actual facts.

I have not seen the results obtained by other expeditions and can therefore only refer the reader to my own "preliminary note" on this subject printed elsewhere.

A reviewer in the August number of *Ciel et Terre* concludes that—because the polar extent of the corona, as shown on photographs obtained by others, is greater than the equatorial extent—my theory does not hold good, as the predicted form shows the opposite arrangement! While it is quite true that some of the particularly brighter streamers of the *outer corona* give this general impression, still, on my photographs of the outer corona, the equatorial extent—which is lost in ordinary printing, can be traced to a distance of at least eight solar diameters from the sun, while in the polar direction the last trace of coronal light is lost at something less than one-half of this distance. Now from a provisional study of my own photographs of this eclipse I have no hesitation in making the following statement:

The photographs of the corona (central) *taken by every expedition sent out to observe the eclipse of last April will invariably show that the brightness and extent of the inner corona was greatest in the spot-zone regions!*

In this eclipse (as in all the other eclipses of which I have phottographic copies) the significant fact that the polar brightness and extent of the *inner* corona was actually less than the equatorial, gives strong evidence that the apparently conspicuous polar streamers of the *outer* corona do not have their origin in the Sun's polar region, but are only seen in projection, at the poles, at great distances from the origin, and consequently are comparatively faint at the Moon's outline.

It will be conceded by all that from the very nature of my theory only a general and ideally typical form corresponding to a perfectly uniform distribution of the eruptive forces can be considered in making predictions. Any attempts to predict the actual positions which all the eruptions in the spot-zones will have at some future particular instant of time would evidently be mere guess work.

Now granting for the moment that the *Mechanical Theory* is true, it would still be as impossible to predict accurately the exact form of the corona at some future particular instant of time as it would be to predict all the exact meteorological conditions at a given place for the same instant of time.

To guard against any possible misconception as to the nature of my prediction I specially stated that it was evidently impossible to predict features due to a (most probable) deviation from a symmetrical arrangement of the forces in the spot-zones.

In view of the fact that I had previously a seeming confirmation of my theory, as applied to this eclipse, the criticisms above referred to called for an answer.

For further information the reader is referred to the "preliminary note" already mentioned, and to the full report on this eclipse which is now in preparation.

LICK OBSERVATORY, Sept. 6, 1893.

ENGINEERING PROBLEMS IN THE CONSTRUCTION OF LARGE REFRACTING TELESCOPES[*]

WORCESTER R. WARNER.

The continued and growing demand of astronomers for larger and more far-reaching telescopes has presented an entirely new series of problems, for the solution of which the best talents o the engineer are brought into play.

Size and penetrating power, while most important, are not the only requisites of the great telescopes of to-day; for they must be specially designed and arranged for spectroscopic and photographic as well as for micrometric and visual work. This combination of uses greatly increases the complexity of the problems and the difficulty of their solution. The suggestion has been made periodically for the last fifty years that the proper system of construction for large telescopes is to place the optical axis of the instrument in a horizontal and permanent position on the ground, pointing due south, and to reflect the images of the heavenly bodies into it by means of mirrors. This would at first sight seem a happy solution of the engineering problems, were it not for the fact that in large instruments it introduces optical difficulties well-nigh insurmountable; for the mirrors must be much larger than the objectives into which they reflect the light, and to give good results their surfaces must be optically perfect, and must be mounted so as to be free from deflection in all positions. These conditions are so difficult to obtain that, for large telescopes, this system is practically ruled out, while for small or medium sized instruments, the ordinary construction with a movable tube is much more convenient.

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[*] Read at the Congress of Astronomy and Astro-Physics, Chicago, 1893. For illustration see Frontispiece.

Professor Langley has, however, recently erected at the Smithsonian Institution a 12-inch horizontal refracting telescope, having an 18-inch plane mirror, which is said to be very perfect and successful in its operation. It is the form known as the Siderostat.

Again, much study has been given to a form of telescope known as the Equatorial Coudé, in which the optical axis of the telescope is parallel to the axis of the Earth, and the light of the star is reflected into it by two mirrors. This is very convenient for the astronomer, who can sit in his chair and observe the stars as easily as he can use his microscope; but the loss of light and definition by the double reflection, as well as the deflection of the mirrors, and the varying temperatures to which the different parts of the instrument are subjected, render this construction far from perfect; so the problems incident to mounting the largest telescopes with movable tubes still confront us.

The three largest telescopes in this country, *viz*;—the new 26-inch equatorial of the Naval Observatory at Washington, the 36-inch Lick telescope at Mt. Hamilton, and the 40-inch Yerkes telescope, just completed for the University of Chicago, and now erected in the Manufactures and Liberal Arts building at the World's Columbian Exposition, may serve to illustrate some of the modern methods of solving these problems, and form the subject of this paper. As the last mentioned and largest is the most available for examination, we will confine the discussion to it.

In designing a large telescope, the first element to which the engineer naturally gives his attention is the tube; for, while its office is a very simple one, being merely to hold the objective and the eye-piece in their proper relation to each other, and to enable the astronomer to direct the optical axis to the star, it is an extremely important factor.

The two most essential points in the tube are lightness and rigidity, the former for ease of motion and the latter to reduce flexure to a minimum. The material best calculated to give these two qualities seems at the present time to be sheet steel. Some material having aluminum as a base has been sought for, but thus far none has been found giving the requisite rigidity.

The form of the tube has much to do with its rigidity, a slight increase in diameter at the center serving to stiffen it to a great degree, and cause thinner material to suffice. No form of internal bracing seems so effective as the same amount of material used in the shell itself. In the tubes of the three large telescopes named there is therefore no bracing whatever, all the strains, both in tension and compression being taken by the sheet steel forming the tube.

The tube for the 40-inch Yerkes telescope is 42 inches in diameter at the objective end, 52 inches at the center, and 38 inches at the eye end. The sheet steel forming the tube varies from 7.32 inches in thickness at the center to 1.8 inches at the ends. The total weight of the tube is six tons.

The declination axis carrying the tube is of forged steel, 12 inches in diameter and 12 feet long, its weight being 1½ tons. This runs in segmental babbitt bearings in the declination sleeve, which weighs 4 tons. The polar axis carrying the whole system is of hard forged steel, 15 inches in diameter at the upper bearing and 12 inches at the lower bearing, and weighs 3½ tons.

Just above its upper bearing it carries the main driving gear, weighing one ton and having 330 teeth, by which the movement of the driving clock is communicated to the polar axis.

The great weight of the bearings of these axes is almost wholly relieved, and the resistance changed from sliding to rolling friction by means of three bracelets or live rings of steel rolls. One of these encircles the declination axis near the tube, and one is placed above each bearing on the polar axis. These anti-friction live rings run in steel yokes, and are pressed against the axes by means of adjustable spring levers.

The live ring of rolls which is on the declination axis near the tube is the center of gravity of the system comprising the tube and the declination axis with their attachments, this one series of rolls serving to take the weight off both bearings of the declination axis, and so nearly eliminating friction that less than one pound of direct pressure on the tube is required for each ton of weight moved. This live ring is composed of 16-inch rolls, 5 inches long, and 3 inches in diameter, and carries a total weight of eight tons.

The live ring at the upper end of the polar axis is composed of 16 rolls, 6 inches long, and 4 inches in diameter. This sustains a weight of nearly 20 tons. The end-thrust of all this great weight, due to the angle at which the axis is placed, is taken on a double series of 40 one-inch hardened steel balls.

The methods of balancing the movable parts of the Yerkes telescope have been a special study, with results which seem all that can be desired.

The heaviest accessory to be used with the telescope is the solar spectroscope. With this in position, the tube is accurately balanced. Weights are then placed on the extension of the declination sleeve until the whole system is in balance. When the solar spectroscope is to be removed sufficient supplementary weights are placed at the side of the eye end of the tube, so the balance is not disturbed.

The equatorial head and its bearings supporting the polar axis and the entire movable part of the telescope, is cast in one piece, its base conforming to the rectangular shape of the column.

The column is 11 ft. × 5 ft. at the base, tapering to 10 ft. × 5 ft. at the head. It is cast in five sections, having internal flanges for securely bolting it together. In the upper section is placed the driving clock. A spiral staircase at the south side of the column gives easy access to the driving clock, and also to the balcony surrounding the head.

The Driving Clock is governed by a double conical pendulum, mounted isochronously, and making sixty revolutions per minute.

A driving weight, considerably in excess of the amount required to drive the telescope, is used with this clock, the surplus of power being taken by a friction ring placed just above the pendulum. The arms of the pendulum are so arranged that in operation they always take their natural and theoretical positions, not being swerved therefrom by the action of the power on the friction ring above mentioned. When the clock is unclamped from the polar axis, all the power required to move the telescope is instantly transferred to the friction ring, and the pendulum maintains its theoretical position and normal rate. An electric motor is provided for automatically winding the clock.

All clamps and slow motions, both in declination and right ascension, are operated by handles at the eye end within easy reach of the observer, while the assistant on the balcony can also set the telescope in any position and read the circles. In addition, electric motors are provided for operating all quick and slow motions, and clamps.

These various motions and clamps being operated by the astronomer at the eye-end of the tube either by hand or by means of the electrie motors, and also by the assistant on the balcony, are so arranged that any one method of working them is not interfered with by either of the others. Each motion is therefore always ready for action and no conflict is possible.

Incident to the construction of large telescopes, problems are presented in providing domes to cover them, and elevating floors by means of which their use is made more convenient.

These problems have been very satisfactorily solved, for the domes of the best construction will revolve by a direct power of two pounds per ton of weight moved.

Elevating floors of nearly the diameter of the domes are in successful use with the 36-inch Lick Telescope and also with the 26-inch telescope at the new Naval Observatory at Washington. Both these elevating floors are operated by hydraulic power, the simple movement of a lever sufficing to raise or lower them.

Such is the solution of some of the problems incident to the construction of large telescopes and their equipment to-day. What improvements the morrow may bring forth it were hazardous to predict.

DETERMINATION OF THE LONGITUDE AND LATITUDE OF THE NEW NAVAL OBSERVATORY WITH REFERENCE TO THE POSITION OF THE OLD OBSERVATORY.*

BY PROFESSOR J. R. EASTMAN, U. S. N.

The observations for this work were made by Professor J. R. Eastman, U. S. N., and Assistant Astronomer, A. N. Skinner.

The reference point for both longitude and latitude of the *old* Naval Observatory was the center of the old dome on the main building. The latitude of the transit-circle pier was the same as that of the old dome.

At the *new* Observatory the longitude is referred to the meridian passing through the centre of the clock-room, which is midway between the east and west transit-circle observing rooms. The latitude is referred to the line joining the centers of the east and west transit piers. At the intersection of this parallel with the meridian in the clock-room a metal plate, properly marked, will be inserted in the floor, and this is taken as the reference point for the longitude and latitude of the new Observatory.

The Longitude.—The plan for this work contemplated the determination of chronometer corrections at each station, the telegraphic exchange of chronometer signals at about the middle of each night's observations, exchange of stations by the observers, and the determination of the personal error of each observer each night with the personal equation apparatus. Similar instruments were used at both stations, consisting of a portable transit of 2.5 inches aperture, sidereal break-circuit chronometer, chronograph, a key and switch-board for facilitating exchange of signals, and a personal equation apparatus. The transit, chronograph and switch-board were a portion of the outfit for the

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* Communicated by F. V. McNair, Superintendent of the Naval Observatory.

transit-of-Venus parties in 1874 and 1882, and require no special description. The personal equation apparatus is described in the Observatory volume for 1875. Observations for longitude were made on eleven nights; Professor Eastman observed six nights at the new Observatory, and Mr. Skinner six nights at the old Observatory. The values of the scale divisions of all the levels were determined before the observing began by means of the level trier belonging to this Observatory. The observations were reduced by the method of least squares, in the usual way to determine the corrections to the assumed chronometer correction and the assumed values of the collimation and azimuth constants, and to obtain the hourly rate of the chronometer.

With the corrected collimation and azimuth constants the computation of the chronometer correction for each star was completed. These corrections for each date were compiled, corrected for rate, and the mean corrections, together with the probable errors, were computed.

The uncorrected results of the exchange of signals were then corrected for the error of chronometer, and the observer's personal equation and the difference of longitude between the two stations, for signals in both directions, was obtained. The mean differences of longitude between the stations for each date are given below, together with the mean of all the dates, computed by using for the weights the squares of the reciprocals of the probable errors.

		s		s
March	9	3.696	±	0.021
"	13	3.630	±	0.028
"	16	3.778	±	0.024
"	28	3.732	±	0.021
"	31	3.677	±	0.025
April	4	3.628	±	0.022
"	5	3.712	±	0.036
"	21	3.624	±	0.021
"	24	3.599	±	0.018
"	27	3.746	±	0.018
"	28	3.632	±	0.018
Mean		3.6738	±	0.012

The transit at the old Observatory was mounted on the old transit circle pier 76.8 feet = $0^s.0656$ *west* of the reference meridian. The transit of the new Observatory was mounted on the west transit-circle pier 81.8 feet = $0^s.0690$ *west* of the reference meridian. Therefore, from this determination, the reference meridian of the *new* Observatory is

$$3^s.670 \pm 0^s.012$$

west of the meridian of the *old* Observatory.

The Latitude.—The two Transits were used as zenith telescopes to determine the approximate difference of latitude between the *old* and *new* Observatories.

The same observing list of stars was used at both stations, and practically the same stars were used each night, at each station.

The observations at the *old* Observatory were made by Mr. Skinner and those at the *new* Observatory by Professor Eastman.

The values of one revolution of the micrometer screws were determined by Professor Eastman by rotating the micrometer 90° and observing the transits of stars, between 54° and 84° north declination, over the single thread used in the observation, as it was moved forward over uniform spaces until the whole range of the thread, during the observations, was covered.

At the *new* Observatory *nine* stars were observed and the value of one revolution of the screw was found to be 68″.970.

At the *old* Observatory *eleven* stars were observed and the value of one revolution of the screw was found to be 68″.601.

An average of nine pairs of stars were observed each night. The mean result of each night's work at each station is given below, together with the adopted mean of the observed latitudes of each Observatory.

	OLD OBSERVATORY.	NEW OBSERVATORX.
May 8	+ 38° 53′	+ 38° 55′ 14″.05 ± 0″. 20
9	38″.22 ± 0″. 23	14 .15 ± 0 . 19
10	38 .17 ± 0 . 12	14 .10 ± 0 . 10
11	38 .25 ± 0 . 16	14 .03 ± 0 . 16
Mean	+ 38° 53′ 38″.20 ± 0″.018	+ 38° 55′ 14″.08 ± 0″.015

As these observations were made at both stations with precisely the same apparatus, using the same stars, the probable error of a single night's work at each station was found, by treating the above seven results together, to be 0″.031, with the resulting probable errors of the mean results at each station as given above.

The observed difference of latitude between the two reference points is

1′ 35″.88 ± 0″.023.

Assuming that the adopted latitude of the *old* Observatory,—+38° 53′ 38″.80, was correct, we have, from these observations, for the latitude of the *new* Observatory,

+ 38° 55′ 14″.68.

On the assumption that the adopted longitude of the *old* Observatory, $5^h\ 8^m\ 12^s.04$ from Greenwich, is correct, we have, from this work, for the longitude of the *new* Observatory

$5^h\ 8^m\ 15^s.71.$

ORBIT OF THE DOUBLE STAR *OΣ* 224.

PROFESSOR S. GLASENAPP.

This star has described arc of 60° since its first observation in 1842. Although such an arc is generally too small to give a good orbit, in this case we have to do with fairly good measures, and can obtain elements which may be considered as a sufficiently good approximation.

We have the following observations of *OΣ* 224:

t	θ °	ρ ″	Observer	t	θ °	ρ ″	Observer
1842.24	13.66	0.35	Mädler	72.28	333.4	——	Dembowski
44.31	20	——	OΣ	.31	336.8	0.55	OΣ
45.31	13.62	0.20	Mädler	74.22	323.4	——	Dembowski
51.27	352.6	0.48	OΣ	75.29	329.9	——	"
.28	17.52	0.25	Mädler	79.32	315.72	0.35	Schiaparelli
57.34	13.6	——	Secchi	80.16	334.3	0.62	Burnham
61.26	348.8	0.59	OΣ	81.25	316.66	——	Doberck
66.27	336.2	——	Dembowski	82.27	309.93	——	"
67.34	338.8	——	"	83.29	335.12	0.55	Engelmann
68.34	342.4	0.5	"	84.21	326.90	0.55	Perrotin
70.16	339.4	——	"	.27	323.70	0.52	Engelmann
71.13	332.4	——	"	87.27	315.59	0.53	Schiaparelli
.31	328.4	0.59	OΣ	92.37	313.6	0.48	Burnham

These observations are to be found in an article on OΣ 224 in ASTRONOMY AND ASTRO-PHYSICS, No. 108, by Professor S. W. Burnham.

We form simple arithmetical means for each year and plot these positions on millimeter paper, and draw a line through the points; we obtain $\Delta\theta$ for equal intervals Δt, and then the differential quotients $\frac{\Delta t}{\Delta\theta}$, from which we deduce the values of ρ by the formula:

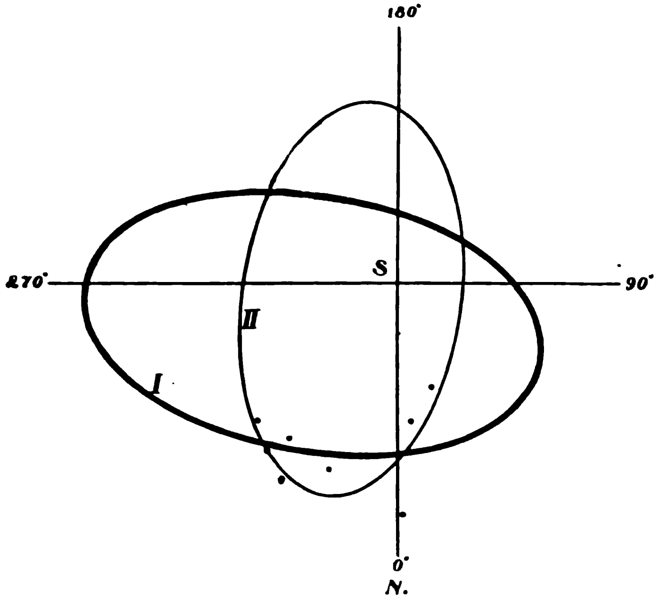
$$\rho = C\sqrt{\frac{\Delta t}{\Delta\theta}}$$

where C is an arbitrary constant. In this manner we obtain the following graphical positions of *OΣ* 224:

θ °	ρ	θ °	ρ	θ °	ρ
30	0.752	350	0.823	320	0.982
20	0.765	340	0.854	310	1.072
10	0.775	330	0.896	300	1.162
0	0.797				

If we lay down these positions on paper, we obtain the arc of an ellipse, whose centre may be easily found, and then the whole ellipse may be drawn. When this is made, we determine the co-ordinates of the intersection of the ellipse with the axis of co-ordinates, which are directed: $+X$ to $\theta = 0°$ and $+Y$ to $\theta = 90°$; thus we have obtained:

$$x_1 = +\,0.796 \qquad y_1 = +\,0.423$$
$$x_2 = -\,0.258 \qquad y_2 = -\,1.302$$



I. Apparent orbit of OΣ 224. II. Ellipse of System II. Observed positions are dark round points.

By means of the formulæ which are given in my work "Orbites des étoiles doubles du Catalogue de Poulkove," St. Pétersbourg, 1889, namely:

$$\alpha = -\frac{x_1 + x_2}{x_1 x_2} \qquad \beta = -\frac{y_1 + y_2}{y_1 y_2}$$
$$\gamma = \frac{1}{x_1 x_3} \qquad \varepsilon = \frac{1}{y_1 y_2}$$

We deduce the values of the four co-efficients of the general equation of an ellipse:

$$\alpha x + \beta y + \gamma x^2 + \delta xy + \varepsilon y^2 + 1 = 0$$

We have obtained:

$$\text{Log}\ \alpha = 0.4183$$
$$\text{Log}\ \beta = 0.2031n$$
$$\text{Log}\ \gamma = 0.6875n$$
$$\text{Log}\ \varepsilon = 0.2591n$$

The fifth co-efficient will be determined by the co-ordinates x_3, y_3 of a point not lying on the axis of co-ordinates by means of the formula:

$$\delta = -\frac{1 + \alpha x_3 + \beta y_3 + \text{[illegible]}^2 + \varepsilon y_3^2}{}$$

We have determined δ by three points and have obtained an arithmetical mean:

$$\text{Log}\ \delta = 9.8616$$

From the formulæ of Kowolsky we obtained the following elements:

$$\begin{array}{ll}
T & = 2031.71 \\
U & = 232.9 \text{ years} \\
n & = -1^{\circ}.5459 \\
\Omega & = 73^{\circ}.06 \\
\lambda & = 59^{\circ}.64 \\
i & = 57^{\circ}.95 \\
e & = 0.54
\end{array}$$

It appeared advisable to apply some corrections to these elements, and after forming equations of condition and solving them by the method of least squares, we found the corrected values of n, T and U:

$$\begin{array}{ll}
n & = -1^{\circ}.6096 \\
U & = 223\ .7 \text{ years} \\
T & = 2025.90
\end{array}$$

The semi-major axis was found from eight mean positions; $a = 0''.65$.

The following are the elements of $O\Sigma$ 224:

$$\left.\begin{array}{ll}
T & = 2025.90 \\
U & = 223.7 \text{ years} \\
n & = -1^{\circ}.6096 \\
\Omega & = 73^{\circ}.06 \\
\lambda & = 59\ .64 \\
i & = 57\ .95 \\
e & = 0.54 \\
a & = 0''.65
\end{array}\right\} \quad (\text{I}).$$

On comparing computed and observed places it appeared that an improvement might be effected by giving the apparent orbit more curvature. A second apparent orbit was therefore found as indicated in the figure by the faint ellipse, while the elements (I) correspond to the apparent ellipse indicated by the heavy line.

$$\left.\begin{array}{ll}
T & = 1976.81 \\
U & = 144.0 \text{ years} \\
n & = -2^{\circ}.4997 \\
\Omega & = 175^{\circ}.3 \\
\lambda & = 283^{\circ}.7 \\
i & = \ \ 59\ .6 \\
e & = 0.433 \\
a & = 0''.52
\end{array}\right\} \quad (\text{II}).$$

After comparing the computed and observed places according to these two sets of elements, it appears that elements (I) will be the most probable at present obtainable.

COMPARISON OF THE ELEMENTS I WITH THE OBSERVATIONS.

t	θ_o	θ_c	$\theta_o - \theta_c$	ρ_o	ρ_c	$\rho_o - \rho_c$	Observer.
	°	°	°	″	″	″	
1842.24	13.7	21.3	− 7.6	0.35	0.42	− 0.07	Mädler
44.31	20 ±	17.8	+ 2.2	——	0.42	——	OΣ
45.31	13.6	16.1	− 2.5	0.20	0.42	− 0.22	Mädler
51.27	352.6	6.1	− 13.5	0.48	0.43	+ 0.05	OΣ
.28	17.5	6.1	+ 11.4	0.25	0.43	− 0.18	Mädler
57.34	13.6	356.3	+ 17.3	——	0.44	——	Secchi
61.26	348.8	350.1	− 1.3	0.59	0.44	+ 0.15	OΣ
66.27	336.2	342.6	− 6.4	——	0.46	——	Dembowski
67.34	338.8	341.1	− 2.3	——	0.46	——	"
68.34	342.4	339.7	+ 2.7	0.5	0.46	+ 0.04	"
70.16	339.4	337.1	+ 2.3	——	0.47	——	"
71.13	332.4	335.8	− 3.4	——	0.48	——	"
.31	328.4	335.6	− 7.2	0.59	0.48	+ 0.11	OΣ
72.28	333.4	334.3	− 0.9	——	0.48	——	Dembowski
.31	336.8	334.2	+ 2.6	0.55	0.48	+ 0.07	OΣ
74.22	323.4	331.8	− 8.4	——	0.49	——	Dembowski
75.29	329.9	330.4	− 0.5	——	0.49	——	"
79.32	315.7	325.6	− 9.9	0.35	0.51	− 0.16	Schiaparelli
80.16	334.3	324.6	+ 9.7	0.62	0.51	+ 0.11	Burnham
81.25	316.7	323.3	− 6.6	——	0.52	——	Doberek
82.27	309.9	322.2	− 12.3	——	0.52	——	"
83.29	335.1	321.1	+ 14.0	0.55	0.53	+ 0.02	Engelmann
84.21	326.9	320.1	+ 6.8	0.55	0.53	+ 0.02	Perrotin
.27	323.7	320.0	+ 3.7	0.52	0.53	− 0.01	Engelmann
87.27	315.6	316.9	− 1.3	0.53	0.55	− 0.02	Schiaparelli
92.37	313.6	312.0	+ 1.6	0.48	0.57	− 0.09	Burnham

The position of the satellite during the next years will be found in the following ephemeris:

t	θ	ρ	t	θ	ρ
	°	″		°	
1895.30	309.4	0.59	1915.30	294.4	0.69
1900.30	305.2	0.62	1920.30	291.3	0.71
1905.30	301.3	0.64	1925.30	288.4	0.73
1910.30	297.8	0.66	1930.30	285.6	0.75

In several years it will be possible to see which of the systems, I or II, is nearer to the real orbit. We give here a comparative ephemeris computed with the systems I and II:

EPHEMERIS OF *OΣ* 224.

	Elements I.		*Elements II.*			*Elements I.*		*Elements II.*	
t	θ	ρ	θ	ρ	t	θ	ρ	θ	ρ
	°	″	°	″		°	″	°	
1890.30	309.4	0.59	306.9	0.45	1915.30	294.4	0.69	269.4	0.37
1900.30	305.2	0.62	299.0	0.43	1920.30	291.3	0.71	258.0	0.37
1905.30	301.3	06.4	290.1	0.40	1925.30	288.4	0.73	246.6	0.37
1910.30	297.8	0.66	280.2	0.38	1930.30	285.6	0.75	235.5	0.48

Astronomers, possessing larger telescopes, should give attention to this double star. The position for 1880 is the following:

$$\alpha = 10^{h}\,33^{m}.4$$
$$\delta = +\,9^{\circ}\,28'$$
$$\mathrm{Mg} = 7.2 - 9.2$$

August 1893.

Astro-Physics.

THE TWO MAGNETIC FIELDS SURROUNDING THE SUN.*

FRANK H. BIGELOW.

It is my privilege, by permission of the chief of the U. S. Weather Bureau, to draw upon the material that has been acquired in an extended investigation of this subject, during the past two years, for some of the statements contained in this paper. Indeed the present reading is the first communication of part of the results to the public, though from time to time preliminary announcements of progress have been made.

The general subject has been one of deep interest to scientists, and much has been done toward its elucidation. The observed facts pertaining to solar physics, to terrestrial magnetism and to meteorology have been such as to render it very probable that these three distinct branches of science are in reality but parts of one more general, cosmical science. The periodic occurrences of manifestations of energy in the sun-spots, the solar corona, the faculæ, and the prominences, on the one hand; the aurora, variations of the terrestrial magnetic field, and fluctuations of the meteorological elements on the other, together with a few isolated observations of the spasmodic actions of the same, have all indicated a fundamental system of physical forces embracing the Sun and the Earth in its operation. The great distance separating these two members of the solar system from each other has, however, been raised as a barrier to the possibility of any such direct action of the Sun on the Earth, and therefore the Newtonian Law of Gravitation has alone been recognized as the bond of union, supplemented by the light radiations through the intervening ether. All the theoretical discussions as to the possibility of a magnetic influence of the Sun at the distance of the Earth have pronounced against the same, those who still hoped for the other verdict being able to sustain their conjectures only by some general statements regarding the electrical and magnetic nature of the Sun.

In spite of the rather unpromising aspect of the problem, I have for a number of years devoted my efforts to obtaining evidence for or against this cosmical relation between the Sun and the Earth through magnetic fields, being greatly incited to such work by the logical consequences of Maxwell's electro-magnetic theory

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* Read at the Conrgess of Astronomy and Astro-Physics, Chicago, August, 1893.

of light, which apparently proven to be true by laboratory experimentation, must have other terrestrial manifestations than heat and light alone. For if the ether is capable of transmitting very rapid oscillating electric vibrations through 93,000,000 of miles it must be accompanied by the magnetic wave in quadrature, which from its great frequency would constitute a steady magnetic field of force, the axis parallel to the direction of the rays of light. If the Earth itself is a polarized magnetic sphere, immersed in such a field, the angles between the magnetic axis such as are determined by known astronomical relations, then the lines of force of this uniform field must be inflected to the Earth at certain angles, pass through it and leave the same at other proper exflected angles. If it were possible to disentangle this field from the permanent magnetic field, and to show its action as a whole, the result would be the long looked for solution of the problem of the variations of the diurnal and annual directions of the magnetic needle near the surface of the earth. It would necessarily be implied that such an electro-magnetic or radiant field has arisen in the atomic oscillations of the constituents of the photosphere of the Sun, communicating their vibrations to the ether, and propagating the radiant energy through it in accordance with mathematical laws that have been carefully examined.

Furthermore, if the Sun has a nucleus in which can reside a species of permanent magnetism, having poles of direction and intensity such as are found upon the Earth, it must also be surrounded by wide-sweeping lines of magnetic force, distributed in space according to another system of mathematical laws. The variations in the intensity of this field, due to heterogeneous distribution of magnetic masses within the solar nucleus, and the spasmodic intensifications of such magnetization, would necessarily vary the strength of this field in its several parts. Thus at the distance of the Earth, if the poles of magnetization of the Sun were found to be nearly perpendicular to the plane of the ecliptic, the lines of magnetic force would reach the Earth, also nearly perpendicular to the plane of the ecliptic, would enter the Earth concentrated at the polar magnetic zone in one hemisphere, pass through it in certain directions, and emerge from it on the other magnetic polar hemisphere. Upon such a curving magnetic field might be found such peculiar stream lines as are displayed in the coronal rays and rifts, allowing for the optical distortion due to their projection from a sphere upon a plane perpendicular to the line of vision; there might be found on these lines the impressed energy manifested in the auroral displays, in the terrestrial magnetic storms, in the periodic variations of the normal magnetic field that correspond to the rotation of the solar nucleus upon its axis; and finally it might be possible that the impressed energy of this magnetic cosmical field undergoes transformations that appear in synchronous variations of the atmospheric hydrostatic presure, temperature, relative humidity, electric potential fall, and general weather conditions, just as is well known to be the case with the transformations of the impressed energy of the electro-magnetic field. If all this were true then the Sun would generate two distinct magnetic fields, one from the photosphere and one from the nucleus; the former would pass through the ether by its rapid rectilinear vibrations in plane waves, and the latter by circular or vortical rotations within the ether, assuming this to be the correct view of what magnetic ether lines are; the Earth would then be traversed by at least three fields of magnetic force, the lines of permanent magnetism, those from the electro-magnetic or radiant field, and those from the magnetic or coronal field, the space just outside the surface of the Earth being penetrated by these three differently directed vector forces. In meteorology these two fields would be treated as two distinct types of solar radiation, one visible and heating, the other invisible and cooling the atmosphere, while both increase its hydrostatic pressure.

However fascinating such a view of the general problem may appear it must yet be made to depend absolutely upon the data of observation. The difficulties in opening the investigation were two in number, first, the currently accepted view that such a solar field as that from the nucleus would be too feeble for direct observation at the Earth; and second the disentangling of the observations, so as to show such systems of impressed forces deflecting the normal field of the Earth from its mean positions. It was very early perceived that in order to handle sucessfully the immense volume of data accumulated in magnetic and meteorological reports, only the very simplest process of computation could be employed, and that in fact the data must be treated quite independently of the theory just outlined, if the resulting values were to become immediately convincing to scientists. The remainder of this paper will therefore consist of a rapid review of the data employed and the results reached, these latter it may now be said, establishing the theory in a manner that it was not at the outset believed possible.

The methods of computation have already been fully explained in Bulletin No. 2 of the U. S. Weather bureau, "Notes on a New Method for the Discussion of Magnetic Observations," Washington, D. C., 1892. They consist essentially in taking out residuals in rectangular coördinates, the horizontal force giving the north component, the declination the west, and the vertical the inward in both hemispheres. These are then transformed into the equivalent polar coördinates, s the total force, σ its horizontal component on the plane of the horizon, β the azimuth angle of σ with the magnetic meridian, counted from the north through the west, and α the vertical angle between σ and s. The reports of magnetic observatories give these three coördinates tabulated for each of the twenty-four hours and for the calendar months. It was assumed that the diurnal variations, corresponding to the rotation of the Earth on its axis, were due to the forces of the electro-magnetic field, appropriate to a particular magnetic latitude and hour angle, which are impressed upon the normal field of the station. Therefore any station carried about by the Earth in its rotation is immersed in different parts of the impressed field in succession, whence it is only necessary to compute the deflecting forces, equivalent to the observed variations and transfer them simultaneously to a globe so placed as to maintain a steady position relatively to the field, in order to have the system which acts simultaneously over the Earth displayed to the eye. Of course it is not possible to obtain more than a mean result; to take account of the minute changes due to the eccentric position of the magnetic system of the Earth relatively to the axis of rotation, the changes of the Sun in declination in its annual period, and interpret the same at each station would demand a labor of computation impossible to undertake. It is at once seen that the electro-magnetic field being instantaneous in action, the observations of the last half century are available without reductions for secular changes of the field, and because the use of differential variations effectually eliminates the forces of the permanent terrestrial field. In the same way the variations of the mean daily values relatively to the mean of the month were assumed to be due to the action of the solar coronal magnetic field, and not to be merely accidental manifestations of variations due to instrumental errors and other agencies not fully understood. These residuals were treated in the same way, and the coronal field was thus eliminated from the permanent magnetic field of the Earth. The study of these two sets of residuals has fortunately served to clear up much that has been heretofore obscure in these subjects, and vistas of beauty have been opened which promise not only clearer views of the cosmical conditions, but also valuable practical results in several directions.

THE CORONAL MAGNETIC FIELD.

The attack upon the portion of the problem pertaining to the coronal magnetic field, has been conducted from two points, namely, the corona of the Sun, and the terrestrial field, believing that if its action could be detected at these two places, it must be at once conceded that its lines of force fill all the intermediate spaces between the Earth and the Sun with their characteristic curvatures. My results of study on the solar coronas of the eclipses of July 29, 1878, January 1, and December 22, 1889, have already been published.* If it is assumed that the stream lines of the corona are the lines of magnetic torce seen in projection, then measured coördinates $(r.\theta.)$ of points on a single ray will give us the means of locating the ray in space. If

$$N = \frac{8\pi}{3} \cdot \frac{\sin^2\theta}{r},$$

is the equation of a stream line, and $x = r \sin \theta, y = r \cos \theta$, then by elimination from three points, the angle of projection separating the plane of vision through the center of the Sun and the plane containing the ray is approximately,

$$\sec^2\alpha = \frac{x_2^{\frac{4}{3}} y_1^{2} - y_2^{2} x_1^{\frac{4}{3}}}{x_1^{\frac{4}{3}} x_2^{2} - x_2^{4} x_1^{2}}.$$

Thence can be computed the magnetic polar distances of the bases of the rays, the location of the coronal poles on the surface of the Sun, and all the elementary distributions of the system, the strength of the magnetization being, of course, not attainable by the geometrical method. It has been found that the bases of the visible coronal rays are confined to two narrow belts, one in each hemisphere of the Sun, about 15° wide, with the middle parallel at about 34° of coronal polar distance. The magnetic poles are about 4½° in polar distance from the poles of the axis of rotation, the south coronal pole preceding the north coronal pole in longitude by about 102°. Having but three isolated points to work with, derived from the three eclipses, for the momentary location of these poles in space, and separated from each other by many rotations of the Sun, an attempt was made to determine the period of rotation of the Sun, even from such meagre data. The results there published have been entirely superseded by the method which will now be described. The har-

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* 1. American Journal of Science, November, 1890. 2. American Journal of Science, July, 1891. 3. Publications of the Astronomical Society of the Pacific. Number 16, 1891.

DEFLECTING FORCES OF THE RADIANT

Measured from the 30-inch Globe

	2 P. M.			3 P. M.			4 P. M.			5 P. M.			6 P. M	
	s	α	β	s	α	β	s	α	β	s	α	β	s	α
Kingua Fjord	3	−53	10	94	−50	15	93	−47	15	90	−44	20	80	−42
Fort Rae	0	−50	15	89	−46	20	94	−45	20	90	−41	25	82	−40
Point Barrow	6	−45	20	87	−42	25	94	−42	25	95	−38	30	83	−37
Cap Thordsen	6	−40	20	90	−39	25	100	−38	25	97	−34	30	86	−36
Jan Mayen	5	−37	25	90	−36	25	102	−34	25	94	−30	30	84	−36
Bossekop	0	−35	35	80	−33	30	84	−33	30	83	−30	30	72	−35
Sodankyla	4	−30	55	52	−30	45	58	−32	40	62	−32	35	60	−34
Toronto	6	−25	70	26	−28	60	24	−30	55	18	−40	40	14	−43
Washington	9	−24	90	27	+23	70	25	+40	50	23	+42	45	21	+58
Makerstown	9	−21	90	27	+24	75	26	+42	60	24	+44	50	24	+60
Dublin	9	−18	90	27	+24	80	26	+40	65	24	+44	55	24	+58
Pawlowsk	0	−17	90	27	+22	85	25	+39	70	23	+42	65	22	+56
Wilhelmshaven	0	−18	95	25	+20	95	21	+40	80	19	+42	75	19	+54
Greenwich	3	−19	95	25	+19	95	21	+40	80	18	+45	85	18	+54
Paris	3	−20	95	26	+18	95	22	+38	80	18	+44	90	17	+56
Vienna	0	−22	95	26	+18	100	22	+37	85	18	+42	90	16	+55
Pola	0	−25	95	25	+20	95	21	+37	90	17	+45	95	13	+56
Los Angeles	0	−26	95	25	+22	95	21	+38	90	17	+47	100	12	+58
Tiflis	0	−29	85	24	+27	90	20	+42	110	16	+50	110	12	+60
Zi-ka-wei	3	−30	65	20	+45	50	13	+48	115	15	+54	140	16	+32
Bombay	7	−30	340	19	−32	315	16	+30	225	15	+35	195	17	+27
Madras	5	−28	340	18	−30	305	17	+32	220	16	+30	195	18	+24
Singapore	3	−26	335	17	−28	300	17	+32	220	17	+25	200	19	+22
St. Helena	2	−25	335	15	−28	295	16	+30	220	16	+20	200	19	+20
Batavia	2	−25	330	15	−28	290	16	+30	215	17	+15	200	20	+18
Süd Georgien	2	+35	240	32	+30	260	28	−30	270	24	−40	265	21	−40
Cape Horn	2	+36	245	30	+35	260	29	−30	275	25	−40	270	21	−40
Cape Good Hope	0	+37	250	30	+30	260	28	−25	275	25	−38	275	20	−40
Melbourne	0	+38	260	30	+30	265	27	−30	275	24	−37	280	20	−40
Hobarton	8	+37	265	30	+35	265	26	−35	280	21	−40	280	19	−40

MAGNETIC FIELD,

-Model.

.	7 P. M.			8 P. M.			9 P. M.			10 P. M.			11 P. M.			Magnetic Latitude
β	s	α	β	s	α	β	s	α	β	s	α	β	s	α	β	
20	68	−40	25	58	−35	30	55	−32	30	52	−28	30	44	+38	135	+78°
25	70	−37	25	60	−34	30	56	−31	40	54	−24	40	52	+40	140	76
30	72	−36	30	62	−36	35	57	−27	50	54	−20	45	52	+42	145	73
30	70	−34	30	60	−38	40	55	−23	60	55	+25	130	56	+40	150	71
30	60	−33	35	57	−33	45	53	−20	65	53	+30	140	57	+38	160	69
35	50	−30	40	45	−27	45	43	+28	140	44	+30	150	50	+34	180	65
35	42	−25	40	37	−22	50	38	+28	145	40	+30	155	47	+30	185	62
30	10	−44	50	9	−30	45	9	+35	330	8	+28	300	7	+20	270	61
25	20	+56	340	19	+34	310	18	+40	300	17	+24	300	17	−24	295	56
20	22	+53	330	20	+37	305	18	+37	295	17	+22	295	16	−22	300	55
20	21	+48	325	20	+40	305	19	+38	290	18	+22	290	16	−20	300	55
15	21	+45	320	19	+40	310	18	+38	290	17	+27	295	16	−20	300	54
25	19	+40	315	19	+42	310	19	+39	300	19	+30	300	17	+32	305	51
30	19	+38	320	19	+44	310	18	+37	305	19	+35	305	18	+30	305	50
35	17	+38	325	17	+46	315	17	+35	310	17	+38	305	17	+27	305	47
45	16	+40	335	15	+42	310	14	+36	305	15	+39	300	15	+33	305	45
55	11	+45	50	10	+40	295	10	+38	300	9	+41	295	8	+45	300	42
115	11	+47	105	9	+42	140	9	+40	255	9	+45	290	8	+48	295	40
125	12	+44	140	10	+43	150	9	+45	220	8	+53	230	8	+50	240	36
155	18	+40	160	16	+40	175	10	+50	185	10	+60	180	9	+55	180	28
195	19	+30	180	21	+33	180	21	+35	180	20	+33	180	20	+30	185	10
195	21	+30	180	22	+30	180	22	+33	180	23	+30	180	24	+30	185	+ 4
190	21	+30	185	23	+28	180	24	+30	180	24	+27	185	24	+28	190	− 6
190	22	+30	185	24	+28	185	25	+27	175	24	+25	185	24	+25	185	−11
190	22	+30	185	23	+30	185	24	+25	175	24	+25	190	24	+25	185	−15
255	18	−45	215	18	−50	185	20	−50	120	20	−45	100	20	−35	90	−30
255	18	−45	225	18	−46	185	18	−48	125	18	−40	100	18	−35	90	−33
260	18	−45	240	18	−45	190	17	−45	130	18	−40	100	18	−35	85	−34
270	17	−45	300	16	−45	350	16	−45	55	17	−40	70	18	−35	75	−50
280	16	−44	310	16	−46	350	16	−45	65	17	−40	75	17	−38	80	−55

monious relation of all the complex formations of rays and structure to the simple law of magnetic lines of force surrounding a polarized sphere, is such as to render it extremely probable that this is the fundamental law of the corona, from which follows much regarding the constitution of the Sun. If however, it is possible to detect the direct action of these same rays at the Earth's magnetic field, this argument regarding the Sun and the cosmical transmission of energy will attain a safe position for further deductions.

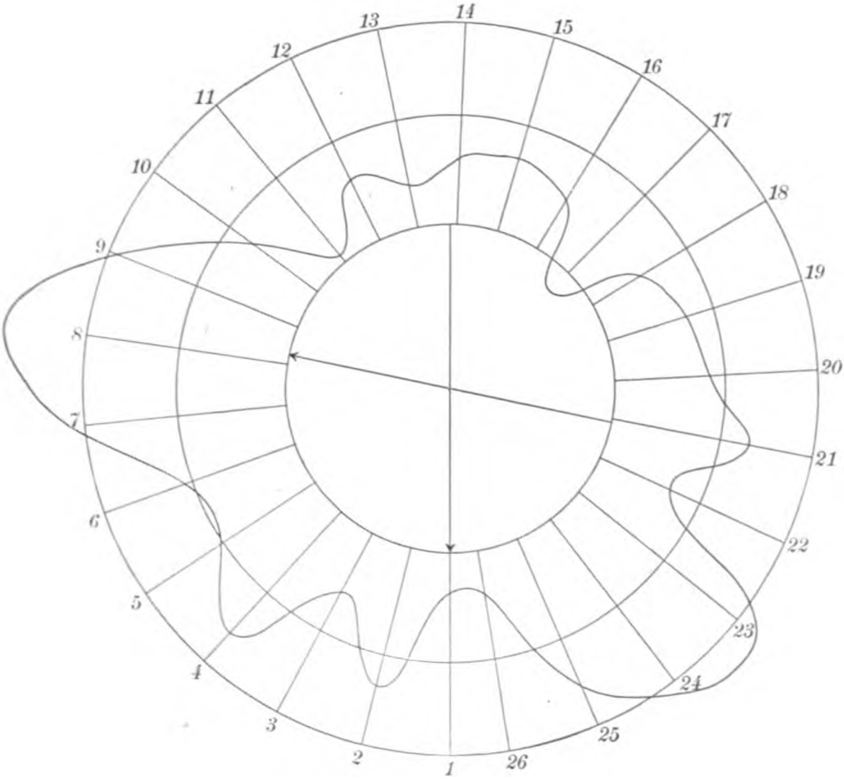
Returning now to the variations of the terrestrial magnetic field, the residuals of the means of the twenty-four observations of each day relatively to the normal mean, derived from the annual mean corrected for the mean of the months, were considered and combined into polar coördinate deflecting forces, just as was done for the radiant field. Certain characteristics at once emerged into view which have enabled me to make important progress in this investigation. Seven European stations for the year 1886, and four more for the year 1887 were completely reduced and the values of s, σ, α, β, tabulated side by side throughout the year. An inspection of the 1886 table showed that certain systematic periodic changes were recurring in about 27 days. Especially was this clearly seen in the azimuth angles which passed through changes of 180° at certain individual dates. The seven stations scattered over Europe, Greenwich, Paris, Pola, Prague, Vienna, Pawlowsk, Tiflis, exhibited deflecting forces pointing north along the magnetic meridians, which would all turn to the south within the same twenty-four hours. There are many other local and sub-periodic characteristics which it must be omitted to describe in this brief paper. In order to prove that these azimuth reversals are cosmical, two stations in America, Los Angeles, California, and Toronto, Canada, were added, as well as Zi-ka-wei, China, and Batavia, Java, covering the hemisphere, and it was found that these simultaneous and periodic reversals of the deflecting forces were entirely independent oi longitude. Furthermore on discussing the corresponding vertical angles α, in spite of their fluttering and uncertain directions at individual stations, arising chiefly from the lack of sensitiveness of the balance magnetometers, it was found that the mean values of α are such that when the field deflects southward, these forces enter the Earth at an angle of about 41°, and that when pointing north they emerge also at 41°. A comparison of the total force s with the horizontal component shows that these vary together in parallel, and are due to the same force, making a mean angle in Europe of 41° with the horizon. A simple process shows that this field is cosmical and approaches the Earth perpendicular to the ecliptic, but is therefrom deflected by the laws of magnetic conduction to enter the Earth within about 7° of the Earth's axis of rotation. The period of the total change was found to be 26.68 days with an epoch, 1887, June 12.22. The period has a series of minor fluctuations in it which I have been able to determine very carefully, and which correspond to an alternate strengthening and weakening of the normal terrestrial field on each side of a mean value.

In order to test the persistence and peculiarities of the resulting curve of variable intensity, such computations were continued for 12 years, from 1878 to 1889 inclusive, for European stations, and all combined by means of an ephemeris constructed from the epoch and period. The following curve is directly obtained by this process. The mean curve has double maxima, on the 17th and 26th days, and double minima, on the 7th and the 24th days.

It shows maximum crests on the 3d, 6th, 11th, 13th, 17th, 22d and 26th days, with corresponding hollows between them. Generally there is a diminution in the intensity between the 3d to the 11th days, and again between the 22d to the 26th, with a stronger field from the 11th to the 22d. Now my dates of reversals were such as to divide up the 26.68 day period into two parts, one of about 8 days and the other of about 19 days, and on reducing these intervals carefully to degrees it gave 102°, as the main sub-division in effectiveness of the period, which agrees so closely with the 100° that had been obtained from the coronal studies, as to render it probable that the same forces were behind the distribution of magnetism on the Sun and this periodic variation of the field at the Earth. Indeed it is only necessary to suppose that the solar nucleus is permanently magnetized, rotates on its axis synodically in 26.68 days, and that this field is swept along past the Earth, the variable intensities being impressed upon the Earth's field and thus detected by the observations.

In order to strengthen this point of view a series of applications of this coronal period have been made with the following results. From four least square discussions of the periodic azimuth changes for the dates corresponding to the 3d, 11th, 17th, and 22d days, the mean correction to the trial period is —0.00072 day, the data embracing the year 1878 to 1889 inclusive. The final period is 26.67928 days = $26^{d}\ 16^{h}\ 18^{m}\ 9.8^{s}$, and the corresponding sidereal period is $24^{d}\ 20^{h}\ 42^{m}\ 59.6^{s}$. This gives the mean

PLATE XXXVIII.



Variation of the intensity of the ***CORONAL FIELD***
in the 26.68 day period, at the ***EARTH.***
***MIDDLE CIRCLE** = 0.000115 dyne;*
increase towards Centre.

daily motion 868′.7, and is the rate of rotation of the external magnetic field, from whence it is inferred that this is the angular velocity of the nucleus of the sun. From the motion of Sunspots on the surface it has been computed that at the equator the velocity is 863′ (Faye), 858′ (Tisserand), 878′ (Spoerer), which agree so closely with the value derived from the coronal field as to force the conclusion that they are measures of the same quantity. Since the magnetic lines of force which reach the earth leave the surface of the sun within 4° of the magnetic poles, it seems probable that the polar and the equatorial regions of the Sun rotate with the same velocity. Hence the so-called acceleration of the equatorial belt of the Sun's surface is only a relative motion as compared with the Sun-spot belts, the true phenomena being that these spot-belts are a westward (anti-rotational) current drift analogous to the terrestrial surface trade winds of the tropics, and due to a general circulation of the Sun's fluid materials.

By means of the ephemeris a model of the stream lines of the solar corona, constrcted in accordance with the theory, can be placed in such a position as the sun occupied relatively to the earth at the time of the three eclipses, assuming only that the first day of our period is the time of the south coronal pole being in the plane perpendicular to the ecliptic, and containing the sun and the earth. When so placed the shadow of orthogonal projection on a plane gives such a picture as the corona should present at the eclipse. The stream lines measured up for computation were enlarged to the model size, copied on transparent paper, and eclipse and model pictures compared directly. The agreement even in details of distribution is a strong proof of the soundness of the theory and the computed period. On wrapping the coronal curve. (see diagram) about a pole, the axes of the locus are seen to be such as already derived, namely at about 102° from the south to the north coronal pole. This is however a problem that is subject to rigorous computation. Many obvious inferences regarding this view of the constitution of the sun might be drawn, and their applications to certain current theories of the sun, its envelopes, the interplanetary spaces and the action of the same on comets and meteorites, but these must here be omitted.

The application of this coronal period to other phenomena is such as to confirm beyond a reasonable doubt these views regarding its formation and the manner of its operation in solar-terrestrial physics. Thus the Greenwich sun-spot areas give the the same fundamental curve, for the years 1878,to 1889 inclusive.

The auroral frequencies taken by stations reporting in the "Monthly Weather review" for 1885–1888 give the same, but less exactly. From the discussion of all the magnetic disturbances of Washington, D. C., for 1889, 1890, 1891, the great impulses all come upon the Earth from north to south, along the coronal field. The same is strikingly shown by the results of the discussion of the magnetic storms, Jan. 4, 5, Jan. 28, 29, Feb. 13, 14, 1892, from ten widely separated stations. The potential-fall of atmospheric electricity from Mendenhall's observations, seven stations, 1886, 1887, taking only clear and fair days, gives the same general curve. Applying it to the meteorological elements, four years at the same European stations, 1886–1889, give a synchronous barometric pressure, with range of ± 2 mm. annually, and directly proportional to the variations of magnetic intensity; the temperatpre varies inversely to the magnetic force in the annual mean of about ± $0^{\circ}.5$ C.; the relative humidity varies inversely about 1.5 %. From counting the numbers of Highs and Lows on the International Charts of 1883 and 1887, the member increases about 20 % with the range of the period. From the U. S. Weather Maps for fifteen years, 1878–1892, it appears that the maximum barometric pressures and the minimum pressures vary with the magnetic field in the 11-year period and also in the coronal period. From the synoptic charts of the North Atlantic for 10 years, 1878-1887, it is found that the hydrostatic pressure of the permanent cyclone decreases with the magnetic period, indicating an action upon the whole atmosphere. From the International Polar Stations of 1882-1883, and the Siberian observations of the same period for the twelve stations, this direct variation of hydrostatic pressure is found more marked, and that too outside the ordinary storm tracks. From tabulations of the weather intensities on a scale of 4, for Europe two years, Washington, D. C., ten years, 1883-1892, Chicago five years, 1888-1892, Bismack, 1883–1892, it is seen clearly that storms tend to accumulate about the maxima of the magnetic curve, and that especially after the 3d, the 11th, the 17th, 22d and the 26th days, the severe weather conditions are most frequent. Herein is an admirable source of long range weather predictions in general terms. The two uncertain factors are *first*, the irregular workings within the Sun's nucleus, and *second*, the lack of uniformity with which this impressed energy coming upon the polar regions bursts forth into the cyclonic systems of the lower latitudes. I have no doubt that much of the difficulty of the solar irregularity can be met by a close watch upon the coronal field through magnetic instruments, especially as the readjustments of magnetism within the nucleus go on with a leisurely pace, judging from the work on these last fifteen years. The second difficulty, as to localizing the outbursts of energy can be met only by a much better knowledge of meteorological physics than we now possess, but the symptoms of change of energy on the daily maps are often apparent to the eye. That the meteorological system is somewhat dependent upon the coronal magnetic field hardly admits of further doubt, and consequently there is ground for some modification of the current theories of storms. This point will be explained before section G. of Meteorology, Congress Auxiliary of the World's Fair.*

In conclusion the radiant electro-magnetic field gives a magnetic strength acting on a unit positive pole of about 0.000135 dyne C.G.S. The mean horizontal component of the coronal field is 0.000085, C.G.S., and of the total force about 0.000115 C.G.S. at the Earth and the variations 0.000040 C.G.S. Hence the intensity of magnetization of the Sun is about 2,340,000 times as much, or 269 dynes, C.G.S. The maximum intensity of magnetization of steel is 1390 dynes (Rowland), hence the normal magnetism of the Sun is about one-fifth that of the maximum of steel. This in the case of ordinary disturbances rises to 4 or 5 times as much, in the most violent to 50 times as much, namely, to 10 times that of the maximum steel. From these data the whole magnetic system of the Sun can be computed, and thence much can be deduced relatively to cosmical propagations of energy, hitherto inaccessible to us. This brief paper cannot do justice to the strength of the proof of the many points compressed into it, but the knowledge of the computations leads me to say that while the forces of these two magnetic fields act in a fluttering way, as is commonly known, yet the action is persistent and accumulative in impressing their forces upon ponderable matter, by the linear or rotational radiant forms of energy. Therefore from the Sun come to the Earth two great supplies of energy, both types of radiations through the ether and possessing very different properties, the one visible to the eye, the other visible to magnetic perceivers.

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* See American Meteorological Journal for September, 1893.

THE CONSTITUTION OF THE STARS.*

EDWARD C. PICKERING.

Our only knowledge of the constitution of the stars is derived from a study of their spectra. This has been done at the Harvard College Observatory as a portion of the work of the Henry Draper Memorial. Photographs have been taken of the spectra of the brighter stars on a large scale, some of them being as much as six inches in length. To photograph the fainter stars, a smaller dispersion is employed and in this way the spectra of stars as faint as the ninth or even the tenth magnitude may be obtained. To study the stars too far south to be visible in Cambridge, expeditions have been sent to South America, and a permanent observing station has been established near Arequipa, Peru, at an altitude of about eight thousand feet. There the southern stars are photographed with instruments similar to those used in Cambridge for the northern stars. A few spectra have been photographed with plates stained with erythrosin, which renders them sensitive to the yellow rays. A portion of the visual spectrum not shown on an ordinary plate is thus photographed. Images of the sodium line "D" in which the two components are clearly visible have been obtained for several stars. In all, many thousand photographs have been collected, including stars in all parts of the sky, from the north to the south pole. The spectra of all the bright stars have been photographed as described above, with a large dispersion, and the spectra of a large portion of the faint stars with a small dispersion. A careful study has been made by Mrs. M. Fleming of the fainter stars, and of the brighter stars by Miss A. C. Maury. From this it appears that while at first sight many spectra seem to be unlike, nearly all of them can be arranged according to a simple system. It is not proposed in the present paper to consider the cause of these differences. For purposes of description, it will be convenient to treat them as if due to differences in composition only, although there is evidence that the actual variation is rather in the order of growth. The spectra of ninety-nine one hundredths of the stars could be imitated by combining in different proportions four sets of lines. These are first, hydrogen; second, a substance presumably calcium in such a condition that it gives the broad lines "H" and "K" which

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* Read at the Congress of ASTRONOMY AND ASTRO-PHYSICS, Chicago, August, 1893.

are the most marked features in photographs of the solar spectrum; thirdly, the substance, or substances, which give the lines characteristic of many of the bright stars in Orion; fourthly, the lines of the solar spectrum omitting those due to hydrogen and calcium. These four classes of lines may be described as hydrogen, calcium, Orion and solar lines. We may now arrange nearly all the visible stars in a sequence such that the spectra change insensibly from each one to the next. At one end of this sequence are such stars as α Virginis, α Eridani, and β Canis Majoris. In them, the Orion lines and hydrogen lines are well marked. The principal Orion lines have wave-lengths 382, 402 and 453, and are sometimes nearly as intense as the hydrogen lines. These spectra are designated by the letter B in the provisional classification adopted in the Draper Catalogue. In the next stars of the sequence the Orion lines have become fainter and the hydrogen lines stronger while the calcium and solar lines are faintly seen. This gives the large class of stars called A in the Draper Catalogue, of which the Milky Way is mainly formed. The stars α Canis Majoris and α Lyræ are examples of this class. The hydrogen lines here so greatly exceed all the others in intensity that in faint spectra they are the only lines visible. The line "H" due to hydrogen has a slightly greater wave-length than the corresponding line due to calcium. When these lines are well defined and about equally intense the H line appears double. This is well shown in such stars as α Cygni in which the hydrogen lines are narrow, but is also distinctly seen in good spectra of α Lyræ and other normal first type stars. In some stars such as α Aquilæ the hydrogen and other lines are broad and ill defined as if the spectra were out of focus. It is possible that this is due to a rapid revolution of the stars around their axes by which the portion near one edge would be receding while that near the opposite edge is approaching. But the velocity required, about a hundred miles a second in the case of α Aquilæ, is so great that such a hypothesis must be accepted with caution. The calcium and solar lines now gradually increase, and the Orion lines diminish in intensity, until they disappear; the hydrogen lines "G" and "h" also diminish. This class of spectrum is called F in the Draper Catalogue. The K line is as intense as the H line and the h and G lines are distinctly fainter. The stars α Argus (Canopus) and β Cassiopeiæ are examples of this class. The solar lines now steadily increase in intensity and the hydrogen lines diminish until the latter are no more intense than some of the solar lines. The typical second type stars are here reached and are represented by α Aurigæ, *α* Centauri, and *α* Ursæ Minoris. They are called G in the Draper Catalogue or E if so faint that only the principal lines are visible. Before reaching this point we may have the hydrogen and solar systems of lines both strong as in *α* Canis Minoris. It is therefore difficult to decide whether both substances are combined in a single star, or whether the star is a close double, one component having a spectrum of the first, the other of the second type. This combination often occurs in double stars. In fact it has long been noticed that in the case of double stars, the brighter component is frequently of a reddish, the fainter of a bluish tint. The spectrum of the first star is then often of the second, while that of that of the second star is of the first type.

The photographs of the prismatic spectra so far described have a uniform density from the F to the H lines, that is from wave-length 397 to 486. As we progress in the series the density of the portion of the spectrum of greater wave-length increases as compared with the other portion. With sufficient dispersion the spectrum is seen to undergo a sudden diminution in density as the wave-length diminishes at the point whose wave-length is 430. The difference in brightness becomes more marked, as the dispersion diminishes, so that when the dispersion is small very faint stars of this class may be recognized by their short spectra, the portion whose wave-length is less than 430 not being visible. Probably the classification of spectra may be carried to fainter stars by means of this property than by any other. The letters H, I, and K are used in the Draper Catalogue to designate such stars. Their spectra may be regarded as forming a second division of the second type. The Sun and *α* Boötis are striking examples of this class, and *α* Tauri is a star still further advanced in the series. As we progress in the sequence a second sudden change in intensity takes place at the point whose wave-length is 476. Unlike the other change the intensity of the portion of shorter wave-length here exceeds that of greater wave-length. This may be regarded as the distinctive feature of the photographic spectra of stars of the third type. The brighest star of thisclass is *α* Orionis. The letter M is used to designate spectra of the third type in the Draper Catalogue. These stars may be further subdivided into four classes, of which the first is that just described. The second is represented by *α* Herculis in which the spectrum is distinctly banded, each band having its edge of greater wave-length bright. The third class is not represented by any bright star. Many of the variable stars of long period have this spectrum when they are not near their maxima. Variable stars of long period, when near maxima, constitute the fourth division which differs from the third only in having one or more of the hydrogen lines bright.

Two classes of spectra must now be considered which are not provided for in the above classification. The first of these consists of the spectra of gaseous nebulæ, the second, that of the stars whose spectra consist mainly of bright lines. The wave-lengths of the lines in both of these classes of spectra appear to coincide with those of the Orion and hydrogen lines. They therefore appear to precede the Orion stars in the sequence described above, but the lines are bright instead of dark. While an ordinary star may be regarded as having a bright nucleus giving a continuous spectrum surrounded by an absorbing medium, the bright nucleus in these objects is wanting, and the spectrum appears to be directly due to the incandescent gas. The reversal in brightness may thus be explained. The gaseous nebulæ can be divided into at least two classes and the bright-line stars into at least three. A few other stars have one or more bright lines in their spectra; for instance, such stars as *γ* Cassiopeiæ, and *φ* Persei in which the F line is bright. They generally belong to the Orion class, and probably so much hydrogen is present in their atmospheres that the absorption is overbalanced by the direct light of the gases.

One other class of spectra remains, that of stars of the fourth type. Their spectra appear to be identical with that of carbon. Almost sixty of these objects are known. They are intensely red and therefore difficult to study photographically. No connection has as yet been established between them and the sequence of spectra described above.

A few peculiar stars like Nova Aurigæ remain, but their number is so small, that for the present each may be considered by itself.

The classification of the stars according to their spectra is so far-reaching that it should be applied to each of their other properties. For instance, of the variable stars it appears that all known Algol stars have spectra of the first type, while long period variables in general are of the third type, and have the hydrogen lines bright when near their maxima, as stated above. This property has led to the discovery of more than twenty objects of this class, and no exception has been found of a star having this spectrum whose light does not really vary. Of the variables of long period which have been discovered visually, the hydrogen lines have been photographed as bright in forty-one, the greater portion of the others being too faint or too red to be studied with our present means. A few variable stars like U Hydræ, R Sculptoris, and B.D. + 62° 596 are of the fourth type. Their variation is small and their red color renders their visual observation uncertain. Variable stars of short period generally have spectra of the second type, but some like β Lyræ present special peculiarities.

The motion of the Sun in space, as derived from stars of each class of spectrum, is a problem of especial importance. The plan of the Henry Draper Memorial provides for the study of each of these and similar problems.

In general, it may be stated that with a few exceptions, all the stars may be arranged in a sequence, beginning with the planetary nebulæ, passing through the bright-line stars to the Orion stars, thence to the first type stars and by insensible changes to the second and third type stars. The evidence that the same plan governs the construction of all parts of the visible Universe is thus conclusive.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., August 5, 1893.

CONCERNING THE NATURE OF NOVA AURIGÆ'S SPECTRUM.*

W. W. CAMPBELL.

The earliest observations of the August, 1892, spectrum of Nova Aurigæ convinced me that it was nebular. There was not the slightest resemblance to any other known type: the continuous spectrum was extremely faint, as in the case of the planetary nebulæ; the spectrum consisted almost wholly of isolated bright lines; the three brightest lines had the relative positions and intensities of the three characteristic nebular lines; and a hasty examination of four well-known nebulæ resulted at once in finding eight other nebular lines which corresponded to eight of the prominent lines in the new star. Without tabulating the results of the comparison with nebular spectra, I stated in September and October that "The spectrum is that of a planetary nebula. . . . Nearly all these lines have been found either in the planetary nebula Σ6 or in the Orion nebula; the lines in Nova's spectrum, however, being displaced four or five tenth-meters towards the violet."

In a learned paper, "*Ueber den neuen Stern im Fuhrmann*," just

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, 1893.

published, Professor Vogel expresses the opinion that the spectrum is not that of a nebula, and inclines to the view that the bright lines are chromospheric. In reviewing my observations Professor Vogel says (page 42):

> "But as Huggins has pointed out, the brightest line in the star spectrum upon which the entire wave-length determination is based, is certainly (bestimmt) not the nebular line, since it is a group of lines, and not a single sharply defined line. It remains certain, therefore, that according to these observations there is very little basis for considering that the star spectrum is that of a nebula."

I must remark first that my wave-length determinations *do not depend upon the wave-length of the line at 500.* The wave-length of each line was determined entirely independently of that at 500, by reference to the artificial spectra of hydrogen, lead, magnesium, mercury, etc. Each line-determination stands upon its own merits. Further, I have always described the lines as abnormally broad,* and have observed that the appearance of the brightest line changes. On August 23, 1892, I measured the positions of two apparent maxima at wave-lengths 5005.9 and 5000.3. In September, October and November,† 1892, the maximum intensity was at the center of the band. In February and April, 1893, the band was broader and nearly of uniform intensity throughout. At no time, however, has there been any excuse for making an error of one tenth-meter in measuring the wave-length of the center of the band.

Since receiving Professor Vogel's paper, I have made a few more visual and long exposure photographic observations of nebular spectra, and without difficulty have found five other lines which also exist in the new star. The results for the nebulæ are given below, without discussion, simply for their bearing upon the character of the new star.

ORION NEBULA.

Only one photograph of the spectrum of this nebula was obtained, in October, 1892. The slit was directed upon the region including and preceding the trapezium. The photographic field ended at wave-length 383. D_3 was observed visually.

D_3	Very faint.	4390	Bright.	4067	Bright.
5007	1st nebular line.	4363	"	4026	"
4958	2nd " "	4341	Hγ, very bright.	3969	H, very bright.
4862	Hβ, 3d nebular line	427	Very faint.	3889	α, bright.
4713	Bright.	424	" "	3868	Bright.
4661	"	4102	Hδ, Very bright.	3836	β, bright.
4473	Very bright.				

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* See ASTRONOMY AND ASTRO-PHYSICS, October, 1892, p. 718.

† *Ibid.*, February, 1893, p. 149.

This list of nineteen lines contains twelve not previously observed. Comparison with the photographic results obtained by Dr. and Mrs. Huggins reveals striking differences. My plate does not show the groups of fine lines obtained by them, and their plate shows none of the bright and very bright lines obtained by me except Hγ. Yet my photograph seems to refer to the same region of the nebula as their photograph of 1888. There are traces of several other lines, but their reality must be tested by another plate.

G. C. 4390, (Σ6).

The measures of D_3 were made visually in 1892. Of the others, those in the first two columns were made in 1892, and those in the last two in 1893. Several faint lines seen in the green have not been measured.

5877	5873	5877		D_3, faint.
5007	5007	5007	5007	1st nebular line.
4958	4958	4958	4958	2d " "
4862	4862	4862	4862	Hβ, 3d nebular line.
......	......	4744	4743	Faint.
472	4716	4714	4712	"
4687	4686	4687	4687	"
......	......	......	4663	Very faint.
4634	4640	4635	4638	Faint.
......	......	......	4610	Very faint.
......	......	460	4595	" "
......	......	......	4574	Faint.
4472	4473	4473	4473	Very bright.
......	4390	4390	4390	Faint.
4365	4364	4364	4364	Bright.
4341	4341	4341	4341	Hγ, very bright.
......	4102	4102	4102	Hδ, " "
......	......	......	4026	Very faint.
......	......	3969	3969	H, bright.
......	......	......	3868	Bright.

So far as I know, twelve of these twenty lines are new.

N. G. C. 7027.

The results in the first column were obtained from a short-exposure photograph in 1892. Those in the last three columns were obtained visually in 1893.

......	D_3	D_3	D_3	Very faint.
......	......	5752	5750	" "
......	5412	5413	5412	Faint.
......	533	......	5413	Very faint.
5007	......	......	......	1st nebular line.
4958	......	......	......	2d " "
4862	......	......	......	Hβ, 3d nebular line.
4741	4745	......	......	Bright.
4716	4716	......	......	Faint.
4688	4688	4688	......	Very bright.
......	4631	......	......	Faint.
4363	......	......	......	Bright.
4341	......	......	......	Hγ, very bright.
4102	......	......	......	Hδ, " "

Seven of these lines appear to be new. That at 5751 coincides with the bright yellow line in the new star; that at 5412 with a prominent line in the Wolf-Rayet stars; and that at 532 is probably the coronal line 5317.

G. C. 4964.

The measures in the first column were made visually in 1892; those in the last two columns photographically in 1893.

532	......	......	Very faint.
......	5007	5007	1st nebular line.
......	4958	4958	2d " "
......	4862	4862	Hβ, 3d nebular line.
......	4744	4744	Faint.
......	4715	4713	"
4684	4687	4688	Very bright.
......	466	4663	Very faint.
......	4638	4642	Faint.
......	4473	4472	Very faint.
......	4364	4364	Bright.
......	4341	4341	Hγ, very bright.
......	4102	4102	Hδ, very bright.
......	......	4067	Very faint.
......	......	4026	" "
......	......	3969′	H, very bright.
......	......	3868	" "

Ten of these lines appear to be new.

G. C. 4373.

These results were obtained from a short-exposure photograph in May, 1893.

5007	1st nebular line	4363	Faint.	4026	Bright.
4958	2d " "	4341	Hγ, very bright.	3969	H, very bright.
4862	Hβ, 3d nebular line	4102	Hδ, " "	3888	α, bright.
4472	Bright.	4067	Bright.	3867	Bright.

Five of these lines appear to be new. The spectrum strongly resembles that of the Orion Nebula.

COMPARISON OF NOVA AURIGÆ'S SPECTRUM WITH THE NEBULAR SPECTRA.

The results for the nebulæ are given in the first five columns of the following table. In the sixth column are the measured wave-lengths of seventeen lines in the Nova's spectrum, and in the seventh column are their intensities. It must be explained that the intensities given above for the nebulæ are from the photographs, while those for the brightest lines in the Nova are visual and those for the faint lines in the photographic region are estimated from the photographs in terms of the brightness of the line 436. Estimates of brightness can be made only roughly from my photographs, since for a given position of the slit, light of one given wave-length only will enter the slit properly, owing to the large chromatic aberration of the 36-inch lens.

I have omitted from my original list of lines those at (557) and at 5268, for the reason that they were too faint to permit an accurate determination of their positions. The former was visible in a small spectroscope with low dispersion, but was invisible in the large spectroscope. The wave-length assigned to it by me is a mere eye estimate, and it could easily be the line 554 observed by Professor Vogel in several planetary nebulæ. The line 5268 was visible in the large spectroscope with difficulty, and only one setting of the micrometer wire upon it was attempted. But Professor Vogel has also observed a similar line at 527 in G. C. 4373 and the Orion Nebula (*Scheiner's Spectralanalyse*, pp. 248, 250). I have not searched for lines at these places, since the wave-lengths in the case of the two Nova lines are not well enough fixed to make a successful search of any value.

Orion Nebula	G. C. 4390 Σ 6	N. G. C. 7027	G. C. 4964	G. C. 4373	Nova Aurigæ.	Intensity.
D_3	5876	D_3	......	......	......	......
......	......	5751	......	......	5750	1
......	......	5412	......	......	......	......
......	......	5313	532	......	......	......
5007	5007	5007	5007	5007	5002	10
4958	4958	4958	4958	4958	4953	3
4862	4862	4862	4862	4862	4857	1
......	4743	4743	4744	......	......	......
4713	4714	4716	4714	......	471	0.1
......	4687	4688	4686	......	4681	0.4
4661	4663	......	4663	......	......	......
......	4637	4631	4640	......	4630	0 7
......	4610	......	......	......	460	0.1
......	4595	......	......	......	......	......
......	4574	......	......	......	......	......
......	......	......	......	......	451	0.1
4473	4473	......	4472	4472	4466	0.1
4390	4390	......	......	......	438	0.1
4363	4364	4363	4364	4363	4358	0 8
4341	4341	4341	4341	4341	4336	0.1
427	......	......	......	......	426	0.1
424	......	......	......	......	423	0.1
4102	4102	4102	4102	4102	4098	0.2
4067	......	......	4067	4067	......	......
4026	4026	......	4026	4026	......	......
3969	3969	......	3969	3969	396	Trace.
3889	......	......	......	3888	......	......
3868	3868	......	3868	3867	......	......
3836	......	......	......	......	......	......

I am not certain that any of these nebulæ contain a line near the wave-length 451; but the other sixteen Nova lines are matched perfectly in one or more of them, allowing for the fact that the Nova lines were shifted about five tenth-meters (in August and September, 1892.) towards the violet. The Nova spectrum certainly differs no more from the nebular spectra than the nebular spectra differ from each other.

It can safely be assumed that the lines at 4857, 4336, 4098 and 396 are the well-known hydrogen lines Hβ, Hγ, Hδ and H. The strongest lines in the spectrum, at 5002 and 4953, then represent perfectly the positions and intensities of the well-known 1st and 2d nebular lines. There is no other type of spectrum in which these lines are known to exist. All the other well-determined Nova lines correspond perfectly to well-determined nebular lines. The presence of the chromosphere line 4472 and the four hydrogen lines must be considered as strengthening rather than weakening my argument, since they exist in the nebulæ and are important factors in the definition of a nebular spectrum.

Nearly all the lines in the February, 1892, spectrum of Nova corresponded to the prominent lines in the solar chromosphere, and *vice versa*. Aside from the hydrogen lines, that correspondence has now become a striking discordance.

In view of the broad and multiple character of the prominent lines in the February, 1892, spectrum we would naturally expect the present lines to be broad and complex. These characteristics of the lines in the early spectrum did not prevent us from arguing that they were chromospheric; why should the same characteristics of the present lines prevent us from arguing that they are nebular?

If the present lines are multiple, the problem only becomes more interesting and more hopeful of solution.

If the spectrum is *not conceded to be nebular*, I must ask what else we should expect to find in that spectrum *if it were* nebular.

MOUNT HAMILTON, August 1, 1893.

ADDENDUM.

After forwarding the above to the Secretary for presentation to the Congress, I received and read with great interest the paper on this subject by Dr. and Mrs. Huggins, in the August, 1893, ASTRONOMY AND ASTRO-PHYSICS. Their observations were confined to the three principal lines in the spectrum, and indeed almost wholly to the brightest one of the three. They write that as soon as they directed the spectroscope to the star, (Feb. 1, 1893), they saw at once, even with one prism, that the two principal bright bands which had been described as the "nebular lines" were in strong contrast with these, not single lines but broad bright spaces, diffused at the ends and irregularly bright, which they suspected to be groups of bright lines.

These characteristics of the lines agree perfectly with those described by me one year ago, in my first article on the Nova, except that in addition I observed several changes in the appearance of the brightest line. At that time I wrote . . . "The difficulties in the way of deciding the question arise not from the faintness of the lines but from their great breadth. They are more diffuse than those of any of the planetary nebulæ which I have observed. With the grating the line λ 5002 is at least eight tenth-meters broad, with diffuse edges, and a brighter central region about four tenth-meters broad. On August 30 the line was suspected to be double, and the grating measures of that night refer to a point midway between the two condensations. On Sept. 7 the measures refer to a point of maximum brightness slightly less refrangible than the center of the line." See ASTRONOMY AND ASTRO-PHYSICS, Oct. 1892, p, 718.

As a result of further observations Dr. and Mrs. Huggins conclude that the bands at λ 501 and λ 496 consist of lines more or less bright upon a feebly luminous background, with possibly some absorption lines. Their work in the rest of the spectrum was confined to satisfying themselves, "by a direct comparison, that the line about F was really the hydrogen line in that region."

They wish to speak at present with great reserve concerning the character of the spectrum, since the observations are incomplete; but they "do not regard the circumstance that the two groups of lines above described fall near the positions of the two nebular lines as sufficient to show any connection between the present physical state of the Nova and that of a nebula of a class which gives these lines."

I can readily assent to that conclusion.

But in interpreting the spectrum of Nova we must not limit ourselves to our knowledge of those two bands or groups of lines. The rest of the spectrum must also be considered. Now Dr. and Mrs. Huggins, and several other observers, have found that the intensities and relative positions of the three most prominent lines or bands in this spectrum agree *perfectly*, within the limits of error, with those of the three most prominent nebular lines.* I have observed nineteen lines in the Nova, eighteen

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* My recent observations of these three bands in Nova give for their wave-lengths, λ 5006.0, 4958.3, 4860.2. These wave-lengths have increased or decreased simultaneously since August, 1892.

of which may be said to correspond perfectly to lines in the nebulæ. Herr von Gothard has observed seven lines, six of which he believes to exist in the spectra of several nebulæ. Four of these six coincide with four lines in my list, and the other two are in the ultra-violet, quite beyond the limits of my photographs of the Nova spectrum. Now if only the brightest two of the twenty-one known lines were broad bands or groups of lines, and the other nineteen were narrow and well defined, a question might possibly be raised as to the origin of the two groups. But such is not the case.

The "line about F" is seen with the large telescope to be a band, apparently identical in form with those at the positions of the two chief nebular lines; and likewise, with certainty, those at λ 463 and λ 436. Whether the fifteen fainter lines and the one at λ 575 are also very broad, it is impossible now to say; but in all probability they are. If any *one* of these bands consists of a group of lines, it is very probable that they *all* do; and it would not, then, be a question of identifying each line in each group with some chemical element, but of observing the *arrangement of the lines in the groups*, in the hope of solving the problem of whether the Nova is *one* nebula, or a system of *several* nebulæ.

The lines in the February, 1892, spectrum occupied in general the positions of the solar chromosphere lines; those lines were broad, and many of them were multiple; but those facts did not prevent us from arguing that the spectrum was chromospheric.

The lines in the present spectrum do not occupy the positions of the prominent lines in the February, 1892, spectrum, nor the positions of lines in the solar chromosphere, nor the positions of the lines in any of the bright-line stars; they do occupy the positions of the lines in the nebulæ; the spectrum resembles nebular spectra as closely as well known nebular spectra resemble each other: therefore the spectrum is nebular, and the fact that the lines have remained broad, or may have remained multiple, does not militate against the theory.

MOUNT HAMILTON, Aug. 11, 1893.

PRELIMINARY NOTE ON THE CORONA* OF APRIL 16, 1893†

J M SCHAEBERLE.

The accompanying photographs‡ of the inner corona were madefrom two of a series of eight negatives taken with a forty-foot telescope on 18X22 inch Seed plates, Sensitometer No. 26. The duration of exposures and the approximate times after the beginning of totality are as follows:—

No. of Negative.	Exposure Time.	Approximate times after beginning of Totality.
1	$0^{s}.25$ ±	2^{s}
2	2.00	16^{s}-18^{s}
3	4 00	32-36
4	8.00	50-58
5	16.00	72-88
6	32.00	102-134
7	24 ±	148-172
8	0.25 ±	186 ±

In the 32^{s} exposure nearly the whole area of the 18X22 plate is covered by the corona. The corona was seen projected on the screen inside of the forty-foot telescope several minutes before 2d contact, and although the last exposure was taken nearly a quarter of a minute after totality the inner corona and the prominences are conspicuous features of this plate, except where the Sun's limb has burnt out the detail.

As bearing directly upon the theory of the corona, the photographs taken with five different instruments at the same station show:

1st. That apparently the matter composing the prominences and protuberances visible during this eclipse was in orbital motion. In the prominences the matter is distributed with varying density along elliptical arcs symmetrical with reference to the Sun; in many cases these arcs seem to be partially discontinuous; they vary all the way from a normal line to a nearly tangential curve and attain a maximum altitude of about 80,000 miles.

The protuberances visible during this eclipse are shown to be made up of a large number of bright elliptical streams of matter

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* Observed at Mina Bronces, Chile.
$\lambda = 70^{\circ}\ 19'$, $\beta = -28^{\circ}\ 27.'$ Height = 6600 feet.

† Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

‡ The positive copies from the original negatives were made by Mr. A. L. Colton of this Observatory.

which intersect each other, in projection, at all angles. These streams are so numerous that on the smaller scale photographs this network of lines has the appearance of a continuous surface.

In this note I consider all photographically visible matter exterior to the Sun's surface as forming part of the corona, and for convenience of illustration the higher and conspicuously individual portion of any protuberance is called a prominence; the former during this eclipse attained a mean height of about 20,000 miles while the latter as conspicuous structures rose to a maximum height of four times this amount.

2d. All the remaining visible matter forming the Sun's corona is apparently of a uniform degree of composition and much less dense than the prominences and protuberances, but like them the matter is arranged in the form of (continuous) curved streams of various heights and each returning stream of the inner corona is plainly visible as a portion of an ellipse whose major axis passes through the Sun's center, indicating that the matter forming these streams was ejected from the Sun and is subject to the action of the Sun's gravity. The symmetrical form of these complete arcs (varying again, all the way from a normal line to a nearly tangential stream) indicates that this rare matter suffers practically no resistance to motion due to an atmosphere of the Sun. Structures again which on the smaller plates appear to follow no law are, with the aid of the larger plates shown to be due to the superposition of these elliptical streams. That these arcs are not due to halation caused by the presence of bright prominences follows from the fact that the eccentricity varies as above stated and from the further fact that no visible change of form took place with reference to the true place of the Sun during the Moon's transit. These visible returning streams are much the most numerous on either side of the Sun's equator and attain a height of 200,000 miles or more.

3d. The outer corona is mainly caused by more nearly radial streams of matter wholly similar in appearance to the curved returning streams of the inner corona. The various trumpet-shape outlines so plainly visible on the smaller wide-angle plates are seen to be due to the superposition of individual streams which in many cases can be traced from the Moon's outline on the larger plates to a distance of several solar diameters on the smaller negatives.

In no case have I found the actual structure to be concave towards the Sun's center, and there are only a few cases of very large streamers having apparently greatly inclined initial directions of motion corresponding to very great velocities, the points of eruption being on or near the Sun's limb. The general form o the outer corona is in general agreement with the prediction for a nearly maximum inclination of the Sun's north pole to the line o sight, although the axis of the inner corona cannot be accurately determined owing to the condensed state of the projections in the polar regions. Marked extensions (nearly radial) projecting fa beyond the usual elliptical outline are found on various quadrants, especially so in the north polar regions. I wish to cal particular attention to a curious structure near the middle of th 4th quadrant; the head of this comet-like object is about four fifths of a solar diameter from the Sun's surface; it is visible o all my negatives of the outer corona.

On the Dallmeyer negatives of the outer corona the Zodiaca Light shows faintly to a distance of about eight solar diameters from the Sun.

In my "Mechanical Theory" certain results are deduced for a typical corona produced by streamers uniformly distributed i the spot-zones. Now it is evident that this ideal or perfect form will be the exceptional case, and for the same reason that the visible solar disturbances in the two spot-zones differ not only from each other, but the study of the Sun's visible surface tells us tha the eruptions are not as a rule distributed with exact uniformity in longitude.

The form resulting from an irregular distribution of the streamers can be constructed provided the longitudes of the various points of eruption and the distance from the origin are known. As the observer will in general have a less latitude than a given stream it follows that the normally ejected outgoing matter between the Earth and Sun will in projection curve away from the equator on the west side of the Sun, and on the east side th curvature will be towards the Sun's equator for the reason tha the outgoing streams in both the northern and southern hemispheres will be on the east side of the normals. Just the opposit condition of things will exist for the outgoing streams* on th farther side of the Sun. (See L. O. Report on the eclipse of Dec 1889, Plate VIII). For the incoming streams the inclination i reversed. The resulting form of the corona in any particula quadrant will depend upon the relative amount of ejected matte in the nearer and farther hemispheres of the Sun's surroundings projected in that quadrant. When the observer is exactly in th

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* A distant portion of a normally ejected stream may in projection actually coincide with a tangent to the Sun's disk.

plane of motion the streams will coincide with normals in projection.

A streamer is evidently made up of a number of nearly parallel streams of matter having presumably many streams with divergent directions of motion. At great distances from the origin such a streamer projected nearly in the direction of the Sun will during an eclipse appear to radiate from a considerable arc of the Moon's limb, the amount and direction of the inclination to the normal being governed by the conditions above indicated.

A considerable interval between two such sets of streamers would result in "gaps" or "rifts" in the corona; when such eruptions actually take place on the Sun's limb those streamers which have greatly inclined initial directions of motion may evidently also become visible.

Referring now to the coronal photographs of the April eclipse and numbering the quadrants 1, 2, 3, 4, in the order NE, ES, SW, WN, referred to the projection of the Sun's axis, the observed forms are explained as follows:

In the first quadrant streams both on this and the farther side of the Sun are seen in projection with a preponderance of the former. The same distribution will account for the forms in the second quadrant. In the third quadrant the streams of the farther hemisphere are almost completely eclipsed by those of the nearer hemisphere. Finally in the first half of the fourth quadrant only the streams of the nearer hemisphere are seen while the second, or polar half of the same quadrant has practically the same arrangement as the first half of the first quadrant. The structure in the equatorial regions (giving the appearance of two opposite magnetic poles on the Sun's equator) is in agreement with the theory that the streams of matter are ejected from the spot-zones and subject to gravitational influences. During this eclipse several powerful eruptions were in action near the Sun's west limb.

A discussion of all the material available will be embodied in a report on this eclipse.

Lick Observatory, Aug. 10, 1893.

THE WAVE-LENGTHS OF THE TWO BRIGHTEST LINES IN THE SPECTRUM OF THE NEBULÆ.*

JAMES E. KEELER.

In No. 11, Vol. II, of the Publications of the Astronomical Society of the Pacific, I published a preliminary account of spectro-

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

scopic observations of Nebulæ with the 36-inch equatorial of the Lick Observatory, containing among other things, measurements of the positions of the brightest nebular lines, and a table giving numerical values for the motion of various planetary nebulæ in the line of sight. These observations were afterwards considerably extended, and the results embodied in a memoir which will be published in due time by the Lick Observatory.

As the publication of this memoir has, however, been delayed, and as my final values for the positions of the principal nebular lines, although they have been quoted from my manuscript by a number of writers, have not appeared in print in a suitable form for reference, it seems to me desirable to give the results for these lines in advance, leaving the individual measures and a description of the methods employed, together with other observations of stars and nebulæ, to the memoir above referred to. I wish also to point out the cause of slight differences in the numerical results given in my previous papers.

The instruments employed in these observations were the 36-inch equatorial and the large spectroscope of the Lick Observatory. The spectroscope was furnished with a Rowland grating, and the nebular lines were observed in the third and fourth spectra. In the fourth spectrum the dispersion was nearly equal to that of twenty-four 60° flint prisms, and the effective aperture of the spectroscope was 1.08 inch. The employment of this dispersion, which would be considered large even in solar spectroscopy, was possible only by virtue of the extreme homogeneity of the nebular radiations, their spectral lines appearing as strictly monochromatic images of the slit. The positions of the lines were micrometrically determined with reference to known metallic lines.

In my preliminary paper the normal position of the chief nebular line was taken to be λ 5005.68 on Angström's scale, a value which was the average of the positions of this line in all the nebulæ I had observed up to that time. By "normal position" is meant the position of the line in the spectrum of a nebula at rest relatively to the observer. As nearly all these nebulæ were in that quarter of the heavens which the solar system was approaching at the time of observation, the wave-length given above is too small by an uncertain amount. The third nebular line (due to hydrogen) not having been observed, and the origin of the principal line being unknown, this result was the best that could be obtained under the circumstances. The position of the second line was λ 4957.7 (Angström), and as it was referred to that of the first, it was subject to the same uncertainty.

In October, 1890, I succeeded in obtaining comparisons of the third line in the spectrum of the Orion nebula with terrestrial hydrogen, and found that the nebula was receding from the solar system at the rate of 10.7 ± 1.0 miles per second. The position of the chief nebular line, corrected for the displacement caused by this motion, was λ 5005.93 on Angström's scale, and this result is affected only by errors of observation and of the wave-lengths of the lines chosen as standards of reference. The results were published in the Proceedings of the Royal Society, Vol. 49, p. 399,

Reduced to Rowland's scale, the wave-length of the chief line, according to these observations, is λ 5006.71; corrected for errors, subsequently determined, in the wave-lengths of the reference lines it is λ 5007.01.

Later in 1890, and in 1891, I succeeded in obtaining accurate comparisons of terrestrial hydrogen with the third line in the nebula G. C. 4390, which is situated in a part of the heavens nearly opposite to the nebula of Orion. The latter nebula was also frequently re-observed, and these independent results were in complete accordance. Many measures were also obtained of the second nebular line, both with reference to the principal line and to standard metallic lines.

Reduction of all these observations brought out clearly the rather remarkable fact that the measures of these faint nebular lines were much more accurate than were the positions of the metallic lines which I had used as standards, and which I had taken from the best tables then available. Micrometric measures were made with the Lick Observatory spectroscope of such lines as were close enough for this method, and the individual results for each nebular line were thereby brought into excellent agreement, but the instrument was not adapted to the precise measurement of large intervals. Finally I obtained from Professor Rowland his then unpublished measures of standard metallic lines, and all the work was then found to be in perfect harmony. The results of all the observations, so far as they relate to the positions of the nebular lines, are as follows:

Normal position of the chief nebular line on Rowland's scale	λ 5007.05 ± .03
Normal position of the second nebular line on Rowland's scale	λ 4959.02 ± .04

These are the values given in Professor Rowland's New Table of Standard Wave-Lengths, in ASTRONOMY AND ASTRO-PHYSICS, April, 1893.

The greater part of the probable error is due to the comparisons with the third line, which could not be observed with the same accuracy as the first. The motion of the Orion nebula, referred to the Sun, from all the observations, is + 11.0 ± 0.8 miles per second, and the wave-length of the chief line in this nebula, corrected for orbital motion of the Earth, is 5007.34 ± .013.

These results show, (for the first time conclusively), that the two principal nebular lines are not represented by absorption lines inthe solar spectrum.

It is also evident that the use of Angström's scale in Astronomical spectroscopy must be abandoned, not so much on account of its systematic deviation from the true normal scale, as on account of the accidental errors with which it is affected, and which are sometimes of a magnitude that cannot be neglected in the present state of astro-physical research.

CONTRIBUTIONS ON THE SUBJECT OF SOLAR PHYSICS.*

E. R. VON OPPOLZER.

In solar physics, few things would be of greater value than accurate information regarding the constitution, the cause, the heliographic distribution, and the motion of sun-spots.

These spots place us in a position to determine not only the rotation-period and the rotation-axis but also the peculiar rotation-law of the sun.

With reference to the constitution of sun-spots, our notions are already clear. After the experiments of Young and Dunér, there can be no doubt that sun-spots are gaseous and of the same chemical structure as the atmosphere in which they float. From Kirchhoff's law, also, it follows that these spots are simply cooled regions in the solar atmosphere. The existence of storms in the neighborhood of spots has been shown by the spectroscope; and we have, indeed, no ground left for considering spots anything but meteorological phenomena. The explanation of these phenomena must be clearly grasped in terms of meteorology before we pass to other explanations. To look in the direction of electrical effects, as Schuster has lately done, appears especially promising. It is simply a question of solar meteorology. But here one is treading on dangerous ground. For as regards the

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

meteorology of even our own atmosphere, we are not agreed as to the fundamental principles, as witness the discussion between the adherents on the one hand, of the "Convection Theory," on the other of the "Dynamical Theory." This, in spite of the tremendous accumulation of observations.

The science, however, has been materially advanced by the recent application of the kinetic theory of gases, and the mechanical theory of heat to our atmosphere, as well as by the establishment of mountain stations at numerous points on the Earth.

In what follows, we shall derive the condition of equilibrium in the solar atmosphere from the laws of gases and the dynamical theory of heat. To be sure it may be objected that the application of these theories to the solar surface is not admissible. However recent experiments and considerations lead us to think that in the sunspot-layer and the immediately overlying regions, we have to deal with a gas which is in a state of extreme tenuity, a state of rarefaction, indeed, far exceeding that of the Geissler tube. In fact, one might say that he has here to do with a "perfect gas," and that, therefore, the application of the above mentioned theories is more than justified. From the condition of equilibrium, we may then infer certain effects and predict certain motions.

Let us begin with an ideal surface N_0, in which the pressure is p_0 and the absolute temperature T_0. Imagine now a unit of mass to be carried to this surface N_0, from any surface N in which the pressure is p and the temperature T. Let h be the distance from the surface N to N_0. The pressure, as well as the temperature increases with the depth. In case no heat is added to or taken away from the mass-unit, it will undergo an adiabatic compression. The heating thus produced could easily be computed if only the distance h, the variation of pressure and temperature with depth, and the nature of the gas were known.

Whatever be the constitution of the atmosphere, the decrease in pressure, dp, corresponding to an increment in height, dh, obeys the law

$$\frac{dp}{p} = -\frac{\gamma}{RT}\,dh$$

where $\gamma = g'/g$, the ratio of gravity on solar surface to gravity on the earth.

$R =$ constant involved in the law of Guy Lussac and Mariotte, *viz.*: $pv = RT$.

T is an unknown function of h; otherwise one might integrate the equation and obtain immediately the law according to which the pressure diminishes with the height. We are at liberty, however, to *assume* certain conditions. The mass which we brought to surface N_0 was heated adiabatically; but suppose that the temperature of the surrounding atmosphere increased with the depth faster than this adiabatic heating from compression. Then the mass would arrive at surface N_0 with a lower temperature than prevailed in surrounding regions. An upward motion in such an atmosphere would be accompanied by cooling of the mass moved. Such an atmosphere would be in unstable equilibrium. If, however, the temperature increases more slowly than the adiabatic heating, then we should expect a warming of the mass in the lower layers. The atmosphere would then remain in stable equilibrium. There is still an intermediate state possible, in which the transportation of a mass in a vertical direction is unaccompanied by any change in temperature. In this case a mass at the altitude h, where the temperature is T, by transport to a lower surface N_0, where the temperature is T_0, suffers a change of temperature, $\varDelta T$, such that

$$\varDelta T = T_0 - T$$

so that the mass arrives at surface N_0 with temperature T_0. This state might be called the "indifferent" state, or state of neutral equilibrium. From Poisson's law, *viz*:

$$\frac{dT}{T} = \frac{k-1}{k} \frac{dp}{p}$$

and the above equation, we obtain the diminution of temperature due to an elevation of unit distance:

$$\frac{dT}{dh} = -\frac{\gamma}{R} \cdot \frac{k-1}{k} = \theta = \text{constant}.$$

where, $k = \frac{C_p}{C_v}$ the ratio of the specific heats.

Assuming that the solar atmosphere is made up of hydrogen, the diminution of temperature per second [$1'' = 720860$ in.] is

$$\theta = 13740°$$

At a distance of one second above the photosphere, we have therefore, a prevailing temperature 14000° lower than on the surface of the photosphere.

Now the observations of Lockyer and Respighi show that a hydrogen atmosphere surrounds the Sun to the height of 420″, which would indicate a temperature at the surface of the photosphere of no less than 5,600,000°. On the contrary, the latest experiments, touching Stefan's law of radiation and Langley's solar constant, indicate solar temperatures, even allowing for absorption, of between 20,000° and 100,000°. It would appear, therefore, that the *actual* changes of temperature θ occur more slowly than they would in the "indifferent" state, *i. e.*, in the state of neutral equlibrium. And, from what has been said before, we conclude that the solar atmosphere is in a condition of extremely stable equilibrium, so that any motion downwards in a vertical direction is accompanied by heating of the mass moved. If we take the temperature of the Sun as lying between the limits mentioned above, we are driven to admit, even in the most unfavorable case, that a current in passing from an altitude of 1″ to the photosphere, would be heated at least 6,000°. The cooling of the "spot-matter" could hardly, therefore, take place in the upper and cooler regions.

If we inquire what causes are effective in producing a local cooling of the atmosphere, two present themselves. The cooling may be due either to adiabatic expansion which is brought about, it may be by an ascending current, it may be by a vortex, or to some especially favored local radiation into space. To decide between these alternatives, we must refer to a very characteristic phenomenon of spots. The almost constant reversal of lines in the spot-spectrum shows (since these lines belong to the upper layers of the atmosphere) that the cool "spot-matter" is overlaid with a hotter layer. That this is not due to faculæ or prominences is shown by the observations of Hale, who finds that "the bright H and K lines seem to *invariably* extend *entirely* across *every* sun-spot. Both lines are doubly reversed in the faculæ which probably completely surrounded every spot. In the umbra, the reversals are narrower, and *the dark central line is usually absent*."

For spots this appearance is characteristic. Hale explains it as follows: "The single reversals in the umbra, however, probably take their rise in the chromosphere, which presumably overlies the cooler regions of the spot."

The thermal observations of Langley and Frost indicate that the spots radiate more heat and less light than the limb of the Sun.

Since, however, Kirchhoff's law demands that the material of the spots be cool, we can only reconcile these two results by assuming that an abnormally hot layer overlies the spot material, so that the total heat-radiation of this layer and the spot exceeds that of the limb. Frost found spots from which the radiation even exceeded that of the surrounding photosphere. The spots lie sunken in the photosphere, which, as is well known, consists of products of condensation and has therefore a *dust-like* constitution.

Over the spots the products of condensation are wanting; and this again is possible only on the assumption that there is an overlying hot layer which has vaporized the photospheric clouds. Since the light of the photosphere is emitted by the latter, the region over the spot would present the appearance of a depression.

All these phenomena emphasize the view that *over the spot region lies an abnormally hot layer, and that spots are places of extremer alternations of temperature.*

Such a characteristic property as this could hardly be ascribed to an ascending current or to a vortex, aside from the fact that one could hardly look for the same cause to produce spots, faculæ and prominences: for the appearance and heliographic distribution of the last two are very different from those of the spots. The inner portions of a spot present a picture of almost absolute quiet. The single remaining cause of cooling is, therefore, locally increased radiation into space. On this assumption, every objection disappears and the facts of observation are completely explained.

Not only from spectroscopic and thermal observations but also from theoretical considerations. it appears that some light from very great depths of the photosphere makes its way through the upper layers of the photosphere itself. The photosphere must exercise upon itself a tremendous absorptive effect since the thin outer layer [*Dunsthülle*] is a powerful protection against radiation from the depths of the photospheric layer.

Radiation from this layer would be very much favored by clearness and transparency in the upper layers of the photosphere; this in turn, would be the state of affairs when the upper layers were vaporized, and this, in turn again, when an abnormally high temperature prevailed. In short, abnormal heat in the upper layers of the photosphere favors radiation from the lower layers. In these lower, deeper parts is situated the cool "spot-material," while in the upper parts we have a condition of abnormally high temperature. *The phenomena demand, therefore, that we consider sun-spots as produced by extraordinary radiation from the underlying, deeper portions of the photosphere.*

The question now presents itself, whence come these hot layers overlying the "spot material"? Certainly not from regions still deeper, for this would bring about immediate destruction of the spot. Perhaps they are produced by hot winds from still hotter portions of the Sun's surface—possibly from faculæ. Against this view, however, stands the deep-seated position of the spot, and, indeed, its entire structure which points to a more central origin. For the source of the heat we can only look, therefore, to the higher regions. We have already indicated how this might happen, descending currents of the atmosphere being accompanied by considerable evolution of heat. But why should this descending motion not penetrate the "spot-material? In answer, it must be remembered that this descending gas heats itself as it falls, and, by this very operation, exerts upon itself a buoyant effect which finally destroys the downward motion.

It is then to vertical "gradients" that we must look for the cause of these vertical motions. It can be shown that a vertical displacement from an elevation of over 4″ could not take place, since this would be accompanied by a variation of pressure amounting to more than fifty per cent of the whole pressure involved.

We arrive then at the conclusion that spots are produced INDIRECTLY *through a sinking down of masses upon the photosphere, and* DIRECTLY *through extraordinary radiation brought about by transparency of the overlying region.*

In our atmosphere, there occurs a similar phenomenon, first explained by Hann.

Regions of high pressure in our latitude are, in winter, regions of great cold on the surface of the Earth. The Earth is then covered with dense clouds. But observations at high mountain stations tell us this cold extends to a comparatively small height, and that above the cold region the air is exceptionally clear and transparent, and that the temperature is abnormally high. The cold layer on the Earth is overlaid by a warm layer. It can be shown also that the air over such regions is falling; and this explains the clearness and high temperature. This unusual transparency favors radiation into space and thus arises the cooling, and the clouds consequent upon this cooling.

Spörer has shown that currents, in the neighborhood of a spot diverge [*divergiren*] which would seem to indicate that spots are regions of high pressure. Spörer has also pointed out that places from which currents arise ("diverge"), are places at which, later, spots appear; so that I feel justified in considering spots as localities of high pressure; and, so far as their cause and structure are concerned, they are analogous to cold spots on the Earth's surface, determined by a high barometer in winter time. These regions would appear to an observer, outside the Earth's atmosphere, as deep, dark spots in a bright sea of cloud. These dark spots would allow one to get a glimpse of the Earth's surface now and then, provided the surface clouds were not too thick.

On this theory of the appearance and disappearance of sunspots, there is, it must be confessed, ample room for the imagination to play.

At least, adjoining layers of widely different temperatures furnishes opportunity for great and sudden changes in the structure of the spot. The cooled masses are to be considered rather as a secondary phenomenon intimately connected with the descending currents, and related to them somewhat as a shadow is to the shadow-producing body. Old spots disappear with the horizontal displacement of the descending current, and thus make way for new ones. The material of which the spot is composed does not move but simply the current which produces the spot. To discuss the formation of groups of spots would require a more accurate knowledge of the dynamical processes which are going on in regions of high pressure. Since terrestrial meteorology cannot yet furnish us this information, we must forego any discussion of these details.

The reference of sunspots to descending currents sheds some light on their distribution in latitude. Considering suns-pots as regions of descending currents and remembering that, corresponding to these, there must be elsewhere regions of ascending currents, we are led, in view of the fact that the spots group themselves in zones parallel to the equator, to place these ascending currents in the polar regions. This view seems the more probable since the spot-belt sometimes reaches all the way to the equator, while at the same time increased activity appears in the higher latitudes, as indeed, is always the case at time of minimum. Polar regions, then, in the solar atmosphere, correspond to equatorial regions in the terrestrial atmosphere, in that each are places of ascending currents. The Sun thus has two great cyclones, one about each pole. Now consider these arising currents to vary in intensity, alternately increasing and diminishing, and you have the cause of the peculiar law of heliographic distribution discovered by Carrington and Spörer. Imagine an increase in the ascending current at the poles in the time of minimum; the consequence would be that the matter would sink, and spots form, in higher latitudes. With constantly increasing intensity of this current, the lower latitudes would be overstrewn with spots, and a spot-maximum would be the consequence. Let this polar up-rush diminish; the spots disappear from the higher latitudes and only the minimum number of spots remains in the neighborhood of the equator. The current again increases and we have a repetition of these phenomena.

These two polar cyclones bring about a peculiar rotation law in different solar latitudes, a rotation law which must, of course, coincide with that of the solar atmosphere. A mathematical discussion of this atmospheric circulation is, at present, impossible. The facts, however, point to a general up-rush in the neighborhood of the poles; for the polar region is the zone of calm for the Sun. The appearance of the corona has led Bigelow to similar results. According to Trouvelot, the chromosphere during a minimum, that is at the beginning of a polar uprush, shows a mountainous outline, has a piled-up appearance; while during the year preceding a minimum there is, in all latitudes, a comparatively widespread calm.

On this theory of spots, the problems of the rotation of the Sun, the frequency of spots, and their distribution in latitude are all reduced to one, *viz.*, to the problem of a periodic uprush in the polar regions. The careful study of these three problems demands that we refer them to a common cause. The intimate relation between frequency and heliographic distribution is well known. The rotation-law as well appears to depend upon the frequency. Observations of spots can give us, during a single spot-period only a crude idea of any change in the law of rotation. But great things are to be expected from observations by the method of Dunér. To this method, astounding in its accuracy, we must look for a final solution of the problem of solar rotation. In solar physics there is no question of higher importance. Unfortunately Dunér's observations cover a period of three years, and these at a time of extreme inactivity.

ASRTO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The Congress on Mathematics, Astronomy and Astro-Physics.

The Congress on Mathematics, Astronomy and Astro-Physics was opened in the Art Institute, Chicago, on Monday, August 21, 1893, with addresses by Professor George W. Hough, Chairman of the Local Committee, and Professor Dr. Felix Klein, Official Delegate of the German Government. On motion of Professor E. H. Moore the Congress divided into two sections, one of Mathematics and the other of Astronomy and Astro-Physics.

In the Section of Mathematics the following program was carried out:

TUESDAY, AUGUST 22, 9:30 A. M.

PAPERS—

Invariantentheorie, by Professor David Hilbert, University of Koenigsberg, Germany.

Ganzzahlige Gleichungen, by Professor Heinrich Weber, University of Goettingen, Germany.

Kronecker's arithmetisch-algebraische Tendenzen, by Professor Eugen Netto, University of Giessen, Germany.

Ueber die Reduction der binären quadratischen Formen, by Professor A. Hurwitz, of the Polytechnic Institute, Zurich, Switzerland.

On Fifth-Power Numbers, whose Sum is a Fifth-Power, by Artemas Martin, LL. D., of the U. S. Coast and Geodetic Survey.

LECTURES—

On the Definitions of the Trigonometric Functions, by Professor Alexander Macfarlane, of the University of Texas.

Complexe Zahlen, by Professor E. Study, University of Marburg, Germany.

Concerning Matrices and Multiple Algebra, by Professor Henry Taber of Clark University.

On the Algebraic Solution of Equations, by Professor A. M. Sawin, Evansville, Wis.

TUESDAY, AUGUST 22, 3 P. M.

Visit to the German University Exhibit at the Columbian Exposition.

WEDNESDAY, AUGUST 23, 9:30 A. M.

PAPERS—

Zahlentheorie und Geometrie, by Dr. H Minkowski, University of Bonn, Germany.

Geltungsbereich der Taylorschen Reihe, by Professor A. Pringsheim, University of Munich, Germany.

On Interpolation Formulæ and their Relation to Infinite Series, by Professor W. H. Echols, of the University of Virginia.

Résumé de quelques résultats relatifs à la théorie des systèmes récurrentes de fonctions, by Professor S. Pincherle, of the University of Bologna, Italy.

Singuläre Puncte einer algebraischen Curve, by Professor Max Noether, University of Erlangen, Germany.

Sur une intégrale définie qui représente la fonction ζ (s) de Riemann, by Professor M. Lerch, Prague, Bohemia.

LECTURES—

Modern Graphical Developments, by President H. T. Eddy, Rose Polytechnic Institute.

Some Salient Points in the History of Noneuclidean and Hyper-Spaces, by Professor George Bruce Halsted, of the University of Texas.

The Principles of the Elliptic and Hyperbolic Analysis, by Professor Alexander Macfarlane, of the University of Texas.

WEDNESDAY, AUGUST 23, 3 P. M.

Visit to the German University Exhibit.

THURSDAY, AUGUST 24, 9:30 A. M.

PAPERS—

Sur quelques propositions fondamentales de la théorie des fonctions elliptiques, by Professor Charles Hermite, Member of the Institute, Paris, France.

A Formulary for an Introduction to Elliptic Functions, by Professor Irving Stringham, Dean of the University of California.

Ueber die Transformation der hyperelliptischen Functionen, by Professor Martin Krause, Dresden Polytechnic, Germany.

Allgemeine Theorie der linearen Differentialgleichungen, by Dr. L. Heffter, University of Giessen, Germany.

Lineare Differentialgleichungen in der Astronomie, by Dr. Heinrich Burkhardt, University of Göttingen, Germany.

Automorphe Functionen und Zahlentheorie, by Dr. Robert Fricke, University of Göttingen, Germany.

LECTURES—

On Weierstrass' Systems of Abelian Integrals of the First and Second Kinds, by Professor Oskar Bolza, of the University of Chicago.

Spherical Trigonometry, by Professor E. Study, University of Marburg, Germany.

FRIDAY, AUGUST 25, 9:30 A. M.

PAPERS—

A Construction of Galois' Group of 660 Elements, by Professor Joseph de Perott, of Clark University.

Concerning the Formation of Groups, by Professor F. N. Cole, of the University of Michigan.

Krystallographie und Gruppentheorie, by Professor Arthur Schoenflies, University of Göttingen, Germany.

Die continuirlichen Gruppen der Ebene, by Professor Franz Meyer, Clausthal School of Mines, Germany.

Sur l'équation des lignes géodesiques, by Professor Edouard Weyr, of the Polytechnic Institute, Prague, Bohemia.

Einige Sätze vom Schwerpunkt, by Professor V. Schlegel, Hagen, Germany.

LECTURES—

On a Quaternary Group of 2520 Linear Substitutions, by Professor Heinrich Maschke, of the University of Chicago.

A Doubly-infinite System of Simple Groups, by Professor E. Hastings Moore, of the University of Chicago.

FRIDAY, AUGUST 25, 3 P. M.

Visit to the German University Exhibit.

SATURDAY, AUGUST 26, 9:30 A. M.

PAPERS—

Der pythagoraische Lehrsatz in mehrdimensionalen Räumen, by Professor V. Schlegel, Hagen, Germany.

La Géométrographie ou l'art des constructions géométriques, by M. Emile Lemoine, Paris, France.

Régle des anologies dans de triangle et transformations continue, by M. Lemoine, Paris, France.

Nomographie: Sur les équations représentables par trois systèmes rectilignes de points isoplèthes, by M. d'Ocagne, Paris, France.

Note concerning Arithmetical Operations involving Large Numbers, by the Rev. T. M. Pervouchine, Kasan, Russia.

LECTURES—

Concerning the Development of the Theory of Groups during the last Twenty Years, by Professor Dr. Felix Klein, of the University of Göttingen, Germany.

SECTOIN OF ASTRONOMY AND ASTRO-PHYSICS.

In the section of Astronomy and Astro-Physics officers were elected as follows: Chairman, Dr. John M. Thome, Cordoba; Secretary, Professor George E. Hale, Chicago; Committee on Program, Professor P. Tacchini, Rome; Professor J. E. Keeler, Allegheny; Professor G. W. Hough, Chicago; Mr. W. R. Warner, Cleveland, with Chairman and Secretary, *ex officio.*

The following papers were read:

TUESDAY, AUGUST 22.

* On the Physical Constitution of Jupiter, by Professor George W. Hough, Director of the Dearborn Observatory.

* The Two Magnetic Fields surrounding the Sun, by Professor Frank H. Bigelow, U. S. Weather Bureau.

* Electro-Magnetic Theory of the Sun's Corona, by Dr. H. Ebert, Erlangen University, Bavaria.

In the discussion of the last two papers Professor H. A. Rowland expressed his belief in a magnetic condition of the Sun, and remarked that he considered its effect upon terrestrial magnetism a subject well worthy of careful investigation.

* An Absolute Photometric Scale for Spectrum Lines, by Mr. L. E. Jewell, Johns Hopkins University.

In the discussion Professor A. O. Leuschner pointed out that the law of increase in density of a photographic plate strictly proportional to the time of exposure cannot be regarded as correct.

* Variation of Metallic Lines with the Amount of Metal in the Arc, by Messrs. Joseph S. Ames and L. E. Jewell, Johns Hopkins University.

Photographs of Comet *b* 1893. Drawings of Mars. By Professor W. J. Hussey, Leland Stanford University.

The photographs exhibited were a series showing the changes in Comet *b* 1893, taken with a portrait lens at the Lick Observatory. The drawings of Mars were made with the 36-inch telescope during the last opposition.

WEDNESDAY, AUGUST 23.

* On a Practical Method of Determining Double Star Orbits by a Graphical Process, and on the Elements Ω and λ, by Dr. T. J. J. See, University of Chicago.

In the discussion Professor Leuschner said he fully concurred in the main points advanced in the paper, and thought all present would appreciate the great efforts made by Dr. See and Mr. Burnham to bring order out of the chaos hitherto existing in the elements of Double Stars. Yet it seemed to him that if we continually went back to the original measures to check the results of the graphical interpolation, it might in some cases be useful to employ graphical interpolating curves. The method was essentially one of trial and error, the final result to be found by successive approximations.

Mr. Burnham spoke of the practical work of finding double-star orbits, and said his own experience had fully convinced him that the only logical method was to plat the observations directly, and to draw by trial an ellipse which satisfied the distances and at the same time conformed to the law of areas. This was the

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* Papers marked with an asterisk will be published in ASTRONOMY AND ASTRO-PHYSICS.

method which he and Dr. See had been using, and those present saw from the diagrams exhibited what results they had obtained.

Mr. Burnham fully approved of the proposed method of taking Ω between 0° and 180°, and of reckoning λ in the direction of the motion. These slight changes in the elements would secure uniformity, and would enable astronomers to at once lay down the apparent orbit of any star from the elements, by using the elegant graphical method discovered by Dr. See and published in the August number of ASTRONOMY AND ASTRO-PHYSICS.

* Great Telescopes of the Future, by Mr. Alvan G. Clark, Cambridgeport, Mass.

In the discussion Dr. J. A. Brashear took exception to Mr. Clark's opinion that the objective-maker must be an artist in color. He held that the spectroscopic examination of the color curve afforded the only certain means of securing correction for a given wave-length. Professor J. E. Keeler suggested the desirability of making the upper end of telescope tubes very large, in order that radiation from the metal may not effect the cone of rays. Professor George E. Hale spoke of the importance ol shielding the tube from direct solar radiation, and stated that an electric exhaust fan would be placed at the centre of the tube of the 40-inch Yerkes telescope for the purposeof withdrawing the heated air from time to time in solar work.

Notes on the Construction of the Modern Spectroscope, by Dr. J. A. Brashear, Allegheny, Penn.

A combined Visual and Photographic Objective, by Dr. J. A. Brashear, Allegheny, Penn.

A 12-inch objective made by Dr. Brashear for the Observatory of Beirut, Syria, was exhibited to illustrate this paper. The inner crown glass lens is mounted in a cell, and two flint glass lenses are provided, each in a separate cell of such form that the lens may readily be placed in contact with the crown, and held there without pressure.

On a Perfectly Free Escapement and a Mercury Pendulum, by S. Riefler of Munich, by Professor Leman, Berlin, Germany.

On Double-Star Observations. The Orbit of 85 Pegasi, by Professor S. Glasenapp St. Petersburg, Russia.

* The Bureau of Measurements of the Paris Observatory, by Miss Dorothea Klumpke, Paris Observatory.

At the invitation of Messrs. Warner & Swasey the members of the Congress attended the opening exhibit of the 40-inch Yerkes telescope at the Columbian Exposition on Wednesday afternoon. Professor Felix Klein, Official Delegate of the German Government, conducted the party through the exhibit of the German Universities.

THURSDAY, AUGUST 24.

* The Wave-length of the Two Principal Lines in the Spectrum of the Nebulæ, by Professor J. E. Keeler, Director of the Allegheny Observatory.

In the discussion Professor George E. Hale remarked on the confusion resulting from the use of several standards of wave-length, and moved that a committee be appointed to consider what action, if any, should be taken toward the adoption of an international standard of wave-length. As members of the committee he proposed Professor von Helmholtz of Germany, Professor Mascart of France, Professor Tacchini of Italy, and Professor Keeler of the United States.

The motion was adopted. On motion of Dr. T. J. J. See a committee consisting of Professor Max Wolf, Professor Benjamin W. Snow, and Professor George E. Hale was named by the Chairman to notify the members of the wave-length committee of their appointment. [Professors Mascart, Tacchini and Keeler expressed their willingness to act, but Professor von Helmholtz's numerous engagements made it impossible for him to accept the appointment. Consideration of the question was therefore deferred.]

* Photographic Investigations of the Sun (illustrated with the stereopticon), by Professor George E. Hale, Director of the Kenwood Observatory, University of Chicago.

In the discussion Professor J. E. Keeler said that a letter had been received from Professor K. D. Naegamvala, Director of the Observatory at Poona, India, stating that if it was deemed desirable he might be able to secure funds for purchasing and operating a spectroheliograph at Poona. Professor Keeler then moved the adoption of the following resolution:

Resolved, that in view of the importance of securing an uninterrupted record of the condition of the Sun's surface by means of photographs similar to those obtained by Professor Hale at the Kenwood Observatory, the Congress of Astronomy and Astro-Physics strongly approves of the proposal of Professor K. D. Naegamvala to establish a spectroheliograph at the Observatory of Poona, India, for the purpose of supplementing the work now in progress at Chicago, and hopes that the proper authorities may see fit to provide the necessary apparatus.

In seconding the motion Professor P. Tacchini dwelt at some length on the importance of such photographs of the faculæ in the study of terrestrial magnetic storms. He advocated the establishment of the spectroheliograph not only in Poona, but also at two other stations respectively 90° east and west of Chicago. The resolution was adopted.

* On the Spectra of the Elements, by Professors Kayser and Runge, Hannover, Germany.

In the discussion of this paper Professor J. E. Keeler remarked upon the value of the method suggested by the authors of identifying lines in stellar spectra by determining the presence or absence of other lines in the same series.

* The Wolf-Rayet Stars (illustrated with the stereopticon), by Professor W. W. Campbell, Lick Observatory.

* Concerning the Nature of Nova Aurigæ's Spectrum, (illustrated with the stereopticon) by Professor W. W. Campbell, Lick Observatory.

* Preliminary Notes on the Corona of April 16, 1893, by Professor J. M. Schaeberle, Lick Observatory.

This paper was illustrated by a complete series of lantern-slides made from negatives obtained by Professor Schaeberle at the recent eclipse.

Photographs of Nebulæ and their Spectra (shown with the stereopticon), by Dr. Eugen von Gothard, Director of the Astro-Physical Observatory, Herèny, Hungary.

Among the spectra shown were those of Nova Aurigæ and a planetary nebula as photographed by Dr. von Gothard with a 10-inch reflector and objective prism. The agreement of the two spectra was very stiking.

Photographs of Minor Planets, Meteors, etc., (shown with the stereopticon), by Professor Max Wolf, Heidelberg, Germany.

Photographs of Stellar Spectra (shown with the stereopticon), by Professor A. O. Leuschner, University of California.

FRIDAY, AUGUST 25.

* Photographic Observations of the Minor Planets, by Professor Max Wolf, Heidelberg, Germany.

* A Field for Woman's Work in Astronomy, by Mrs. M. Fleming, Harvard College Observatory.

In the discussion Dr. J. A. Brashear highly praised the astronomical work of women, and Professor W. H. Pickering testified to the efficient service of the women employed at the Harvard College Observatory.

* Recent Investigations at the Cordoba Observatory, by Dr. John M. Thome, Director.

* The Atmospheric Refraction at Madison, Wisconsin, by Professor George C. Comstock, Director of the Washburn Observatory, University of Wisconsin.

* The Infra-Red Spectrum, by Professor S. P. Langley, Secretary of the Smithsonian Institution, Washington, D. C.

SATURDAY, AUGUST 26.

* Is the Moon a Dead Planet? By Professor W. H. Pickering, Harvard College Observatory.

* The Constitution of the Stars, by Professor Edward C. Pickering, Director of the Harvard College Observatory.

Professor J. E. Keeler opened the discussion of this paper, and reviewed the systems of classification of stellar spectra proposed by Secchi, Vogel, Lockyer and others. He expressed his belief that the time has not yet arrived to formulate a complete and wholly satisfactory system of classification.

* Contributions on the subject of Solar Physics, by Dr. Egon von Oppolzer, Vienna, Austria.

* Theory of the Sun, by Dr. A. Brester, Jz., Delft, Holland.

Theory of the Sun, by M. H. Faye, Bureau des Longitudes, Paris.

The Retrograde Rotation of the outer Planets, by Professor W. H. Pickering, Harvard College Observatory.

In accordance with the custom of naming a minor planet at the conclusion of an astronomical congress Professor Max Wolf requested that a name recalling the present congress be given to one of his newly discovered asteroids. He suggested "Chicago" and "Illinoa" as appropriate titles. The former was chosen by vote of the Section.

A vote of thanks to the foreign delegates for their presence and participation in the proceedings of the Section was moved by Dr. J. A. Brashear and carried unanimously.

Professor J. E. Keeler proposed a vote of thanks to the officers of the Section, which was adopted.

The Section then adjourned.

GEORGE E. HALE, Secretary..

Blueness of the Sky at High Altitudes.

Dear Professor Hale:

When in Chicago last I spoke to you about stopping at several points in Colorado on the return to California to see how the sky looked with the naked eye.

We ascended Pike's Peak August 15th on the Cogwheel railway. The summit was scarcely reached before a heavy snow storm set in, accompanied with thunder and lightning, and sky and plains were blotted out by the enveloping clouds. In descending we found the lower peaks—about 7,000 or 8,000 feet high, covered with snow.

While ascending the mountain we had frequent glimpses of the sky between breaks in the clouds, but never in the direction of the Sun. What we thus saw of the sky seemed fairly blue but not a deep dark blue.

That night we remained at Colorado Springs, 6,000 feet, until eleven o'clock. The sky had cleared and was very dark and rich and the stars shone with great brilliancy. Their light, however, was very unsteady to the naked eye, showing that telescopic observations would have been hopeless. The electric lights everywhere made it impossible to tell just how transparent the sky was, but later, 2 A. M., as we were passing through the Royal Gorge (on the Denver & Rio Grande) the sky as seen from the moving train, gave every indication of great purity.

Marshall Pass (11,000 feet altitude) was one of the points where it had been decided to stop over. As there is no hotel at this point we managed, after some entreaty, to secure the rough accomodations that the section house could afford. We remained at the Pass from 6:30 A. M. of the 16th to the same hour of the 17th.

Close north of the section house stands Mount Ouray, a grand peak a little over 14,000 feet high. Joining this and a little lower and nearer the section house is a smaller peak locally called Little Ouray. This will not be far from 13,500 or 13,900 feet high. This latter peak I ascended as time did not permit the ascent of Ouray proper. I reached the top of the peak at 10:30 A. M. and upwards of three quarters of an hour was spent on the summit above the timber line. The day was very beautiful with magnificent cumulus clouds. The sky was a deep rich blue and perfectly pure. Hiding the Sun with one's hat it was possible to look up close to the solar limb. There was no halo or glare at all about the Sun—the sky being a deep rich blue up to the very limb. While I remained at this point and watched the sky it was forcibly impressed upon me that such a sky would offer the highest advantages in any attempt to photograph the corona without an eclipse. The altitude was somewhat trying but not so much so as at Pike's Peak. A bank of snow gave the means of quenching one's thirst.

Descending to the Pass, the sky, though still very pure, was perceptibly whiter. As the day advanced the clouds finally covered the sky and the night was more or less cloudy. I was up off and on the entire night in hopes of seeing the night sky. At 11 P. M. the clouds broke away for a short time in the north and the sky appeared very fine, but was soon quickly blotted out permanently.

The atmosphere in Colorado during the day was remarkably pure and free from dust—the most distant objects coming out with striking distinctness.

At Grand Junction, 4,600 feet (on the same railroad) we were detained until midnight. The sky was very pure and dark and the Milky Way was a striking object.

In crossing the Sierras it was hoped the sky might prove interesting, but at Summit (over 7,000 feet) at mid-day it was whitish and brightened rapidly in the direction of the Sun. The mountains were filled with dust and haze.

In connection with this I would say that on July 18, 1892, I spent the night on Wilson's Peak (site of the Harvard College Observatory station) 6,000 feet altitude, near Pasadena in Southern California. I have nowhere seen a finer, clearer sky. The Milky Way was remarkably clear and bright—the star clouds standing out with a distinctness that gave the impression that they were not far away. The atmosphere seemed to be perfectly steady. It perhaps may sound rather strange, but in looking back over the experience of the past few years, I have hardly seen anywhere as clear and rich a sky as sometimes occurred at Nashville, Tennessee, with an altitude of only 600 feet.

From what I have seen and from a conversation with Professor H. S. Pritchett, of St. Louis, Mo., who has had practical observational experience in Arizona, I should think that an observatory placed on some of the high plateau mesas of Colorado or Arizona, where the altitude is all the way up to 5,000 or 6,000 feet, would be a good place for a large telescope, as there might be less chance of atmospheric disturbances than on a mountain peak.

Very sincerely yours,
E. E. BARNARD.

Photography of the Corona without an Eclipse.—The above letter from Dr. Barnard contains much of interest to those engaged in the study of this problem. At Pike's Peak last June the writer observed the sky near the Sun from various points between the base and the summit of the Peak, and noticed a steady decrease of brilliancy with increase of altitude. At times the sky, as seen from the summit, was very dark, but there was invariably a bright halo surrounding the Sun. Swarms of insects above the mountain had a certain share in producing this effect, but the Sun was really never seen under the best conditions, as clouds invariably covered the sky before it reached the meridian. Before the adjustments of the instruments could be completed, fires broke out in the surrounding forests, and the smoke quickly spread itself over the sky, greatly increasing the brightness of the atmospheric glare.

M. Ricco's attempts to photograph the corona at Catania are described in the July number of the *Memorie della Societa degli Spettroscopisti Italiani.* Dr. Huggins' method was employed, and halos resembling the corona in form were obtained in the photographs. A drawing of one of these images accompanies M. Ricco's very interesting paper. Two circumstances lead one to doubt whether the true corona is here represented. In the first place the exposure seems to have been too short to give such marked extension of the streamers. Again four exposures made during the eclipse of April last (which was partial in Catania), show no effect of the Moon in cutting out a portion of the corona. Hence it would seem that the coronal forms obtained must have had their origin between the Moon and the photographic plate. Great care has been taken in the experiments, and it is satisfactory to know that they will be continued. G. E. H.

The Spectrum of Comet *b* 1893. A few observations of the spectrum of comet *b* 1893 were made at Allegheny, too late for insertion in my note in the August number. On July 21 the sky was unusually clear and the spectrum was seen better than on any previous occasion. The second maximum of the green band was easily visible, and the fluted appearance could be traced clear across the coma. The yellow and blue bands also had a fluted appearance, but the maxima were not sufficiently distinct for measurement. The terminal line of the green band was the brightest part of the spectrum. In each of the other two bands, however, the greatest brightness was not at the edge, but at a place somewhat above it. A photograph taken a few days later also shows this distribution of light in the blue band.

A number of photographs of the spectrum of a Bunsen burner flame were made with the same apparatus, each with a narrow solar spectrum for reference. One of these, on an isochromatic plate, shows the structure of the carbon bands, from the *D* line to the ultra-violet, with beautiful distinctness, notwithstanding the smallness of the scale.

Comparison of these plates with the comet photograph shows no very striking similarity in the upper part of the spectrum. The blue cometary band agrees in position with the blue band of the Bunsen burner, and lines at λ 388 and λ 387 coincide in both spectra; but in the Bunsen burner spectrum the line at λ 388 is the terminal line of a band facing toward the violet, while its appearance in the comet spectrum is that of a band facing the other way. This appearance may be due to the faintness of the photographic impression on the latter plate. The lines are probably identical.

The great band beginning near G, which is the strongest in the spectrum of the Bunsen burner, does not show on the comet photograph. There is however a slight shade near λ 420, which may possibly represent a group of bright lines photographed by Mr. Campbell. On account of smoke near the horizon all photographic observations were made at Allegheny under a great disadvantage and sometimes a plate was exposed for two hours without any result whatever.

JAMES E. KEELER.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR NOVEMBER.

Mercury will be "evening star" during the greater part of November, coming to greatest eastern elongation, 23° east from the Sun, on the evening of Nov. 5. It will, however, then be at nearly its greatest southern declination, so that it can be seen by northern observers only at a very low altitude. In the southern hemisphere the position of the planet will be favorable for observation during the first half of the month. On Nov. 26, at 6 A. M. Central time, Mercury will be at inferior conjunction with the Sun. The planet will then be 1° 25′ north of the Sun's center.

Venus will also be evening star during November and will be in splendid position for observation from the southern hemisphere of the Earth, but northern observers must content themselves with views at low altitudes. The phase of Venus will be a little more than half full and gradually decreasing, while the apparent diameter of the disk will increase from 18″, Nov. 1, to 24″, Dec. 1. The crescent Moon will pass Venus about noon Nov. 12, so that on that evening and the preceding the two brilliant objects will be near together.

Mars will be morning planet and may be seen in the morning twilight but at so low an altitude that observations will be useless.

Jupiter is the object of objects to be observed by amateur astronomers during November. The planet comes to opposition Nov. 18. It will therefore be visible during the whole night, and as its declination is between 18° and 19° north of the equator, its meridian passage will be at a high altitude. The diameter of

Jupiter's disk during this month will be about 47″, so that not only the belts but many small spots and much fine detail on the planet's surface onght to be visible with telescopes of moderate power. No one can mistake this planet, for his splendid brilliancy outshines any other object in the evening sky, with the exception of the Moon. The latter will pass by Jupiter, about 4° to the north, at about 4 o'clock on the morning of Nov. 23. Jupiter's apparent motion will be westward in the constellation Taurus, a little way south of the Pleiades. For the phenomena of the satellite see the tables which follow these notes.

Saturn has just come out from conjunction with the Sun and cannot yet be seen to advantage.

Uranus will be in conjunction with the Sun at midnight Nov. 2.

Neptune is approaching opposition and is at a high northern declination, so that he may be observed under the most favorable circumstances. The trouble with this planet, for amateurs, is that its disk is so small that it cannot be recognized by that with small telescopes, and its motion is so slow that just now it requires two or three days to make the change of position noticeable. In a photograph taken at Goodsell Observatory on the evening of Sept. 21, with the 2½-inch camera, Neptune is on a direct line between the stars *i* and *ε* of the constellation Taurus and about one fifth of the distance from the former to the latter star. During October and November the planet will move only 1° 23′ west and 11′ south from its present position. There is but one star as bright as Neptune within a radius of a degree, or twice the Moon's diameter, and that star is toward the north from the planet, so that it is now comparatively easy to identify the planet.

PLANET TABLES FOR NOVEMBER.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
1893.	h m	° ′	h m	h m	h m
MERCURY.					
Nov. 5	16 17.2	− 24 10	8 57 A. M.	1 16.3 P. M.	5 36 P. M.
15	16 44.7	− 24 25	8 45 "	1 04.3 "	5 24 "
25	16 15.1	− 20 33	7 18 "	11 55.4 A. M.	4 33 "
VENUS.					
Nov. 5	17 53.6	− 26 11	10 33 A. M.	2 52.2 P. M.	7 01 P. M.
15	18 43.8	− 25 59	10 53 "	3 03.1 "	7 13 "
25	19 31.8	− 24 41	10 55 "	3 11.6 "	7 28 "
MARS.					
Nov. 5	13 23.7	− 7 59	4 51 A. M.	10 23.2 A. M.	3 55 P. M.
15	13 48.4	− 10 27	4 47 "	10 08.6 "	3 30 "
25	14 13.7	− 12 48	4 42 "	9 54.4 "	3 06 "
JUPITER.					
Nov. 5	3 44.0	+ 18 38	5 20 P. M.	12 41.2 A. M.	8 02 A. M.
15	3 38.6	+ 18 20	4 36 "	11 56.4 P. M.	7 17 "
25	3 33.0	+ 18 03	3 53 "	11 11.5 "	6 30 "
SATURN.					
Nov. 5	13 14.1	− 5 24	4 32 A. M.	10 13.6 A. M.	3 56 P. M.
15	13 18.3	− 5 48	3 58 "	9 38.5 "	3 19 "
25	13 22.2	− 6 10	3 24 "	9 03.2 "	2 24 "

URANUS.

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
	h m	° ′	h m	h m	h m
Nov. 5	14 35.6	– 14 51	6 32 A. M.	11 34.9 A. M.	4 38 P. M.
15	14 38.1	– 15 01	5 56 "	10 58.0 "	4 00 "
25	14 40.4	– 15 12	5 19 "	10 21.1 "	3 23 "
			NEPTUNE.		
Nov. 5	4 46.7	+ 20 48	6 12 P. M.	1 43.6 A. M.	9 15 A. M.
15	4 45.6	+ 20 46	5 32 "	1 03.2 "	8 34 "
25	4 44.4	+ 20 44	4 52 "	12 22.8 "	7 54 "
			THE SUN.		
Nov. 5	14 44.4	– 14 56	6 41 A. M.	11 43.7 A. M.	4 47 P. M.
15	15 25.0	– 18 42	6 59 "	11 44.8 "	4 31 "
25	16 06.9	– 20 55	7 12 "	11 47.3 "	4 13 "

Minima of Variable Sars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

R. A.................$0^h\ 52^m\ 32^s$
Decl..................+81° 17′
Period............2*d* $11^h 50^m$

Nov. 3	5 P. M.
6	5 A. M.
8	4 P. M.
11	4 A. M.
16	4 "
21	4 "
26	3 "

ALGOL.

R. A...............$3^h\ 1^m\ 1^s$
Decl................+ 40° 32′
Period............2*d* $20^h 49^m$

Nov. 2	9 P. M.
5	6 P. M.
8	3 "
17	5 A. M.
20	2 "
22	11 P. M.
25	8 "
28	5 "

λ TAURI.

R. A...............$3^h\ 54^m\ 35^s$
Decl.................+ 12° 11′
Period.............3*d* $22^h 52^m$

Nov. 3	1 A. M.
6	midn.
10	11 P. M.
14	10 "
18	9 "
22	8 "
26	6 "
30	5 "

R. CANIS MAJORIS.

R. A.............. $7^h\ 14^m\ 30^s$
Decl.............— 16° 11′
Period..........1*d* $3^h\ 16^m$

Nov. 6	1 A. M.
7	4 "
13	midn.
15	3 A. M.
16	6 "
22	2 "
23	5 "

S CANCRI.

R. A.............. $8^h\ 37^m\ 39^s$
Decl................+ 19° 26′
Period............9*d* $11^h\ 38^m$

Nov. 12	6 P. M.
22	6 A. M.

S ANTLIÆ.

R. A.............. $9^h\ 27^m\ 30^s$
Decl...............– 28° 09′
Period........... $7^h\ 47^m$

Nov. 9	6 A. M.
10	5 "
11	5 "
12	4 "
21	6 "
22	5 "
23	5 "
24	4 "

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	IMMERSION Washington M. T.	IMMERSION Angle f'm N pt.	EMERSION Washington M. T.	EMERSION Angle f'm N pt.	Duration.
			h m	°	h m	s	h m
Nov. 14	B.A.C. 7077	6.4	6 22	127	6 56	183	0 34
15	33 Capricorni	5.7	7 05	74	8 19	219	1 14
17	74 Aquarii	6.0	2 14	54	3 23	252	1 09
18	24 Piscium	6.1	11 37	30	12 36	260	0 59
22	τ^2 Arietis	5.3	9 01	125	9 30	173	0 29
24	136 Tauri	5.3	17 51	144	18 30	227	0 39
26	ω^1 Cancri	6.0	13 52	138	14 57	249	1 05

Phenomena of Jupiter's Satellites.

		h	m			
Nov.	2	2	31	A. M.	II	Sh. In.
		3	23	"	II	Tr. In.
		4	51	"	II	Sh. Eg.
		5	38	"	II	Tr. Eg.
	3	5	21	"	I	Ec. Dis.
		7	54	"	I	Oc. Re.
		9	33	P. M.	II	Ec. Dis.
	4	12	32	A. M.	II	Oc. Re.
		2	38	"	I	Sh. In.
		3	01	"	I	Tr. In.
		4	50	"	I	Sh. Eg.
		5	12	"	I	Tr. Eg.
		11	50	P. M.	I	Ec. Dis.
	5	2	20	A. M.	I	Oc. Re.
		6	10	P. M.	II	Sh. Eg.
		6	46	"	II	Tr. Eg.
		9	06	"	I	Sh. In.
		9	27	"	I	Tr. In.
		11	18	"	I	Sh. Eg.
		11	38	"	I	Tr. Eg.
	6	6	19	"	I	Ec. Dis.
		8	46	"	I	Oc. Re.
	7	1	14	A. M.	III	Sh. In.
		2	41	"	III	Tr. In.
		3	01	"	III	Sh. Eg.
		3	56	"	III	Tr. Eg.
		5	47	P. M.	I	Sh. Eg.
		6	04	"	I	Tr. Eg.
	9	5	08	A. M.	II	Sh. In.
		5	38	"	II	Tr. In.
		7	29	"	II	Sh. Eg.
		7	54	"	II	Tr. Eg.
	10	7	16	A. M.	I	Ec. Dis.
		5	22	P. M.	III	Oc. Re.
	11	12	08	A. M.	II	Ec. Dis.
		2	45	"	II	Oc. Re.
		4	32	"	I	Sh. In.
		4	44	"	I	Tr. In.
		6	45	"	I	Sh. Eg.
		6	55	"	I	Tr. Eg.
	12	1	45	"	I	Ec. Dis.
		4	02	"	I	Oc. Re.
		6	27	P. M.	II	Sh. In.
		6	46	"	II	Tr. In.
		8	47	"	II	Sh. Eg.
		9	02	"	II	Tr. Eg.
		11	01	"	I	Sh. In.
		11	10	"	I	Tr. In.
	13	1	13	A. M.	I	Sh. Eg.
		1	21	"	I	Tr. Eg.
		8	14	P. M.	I	Ec. Dis.
		10	30	"	I	Oc. Re.
	14	5	14	A. M.	III	Sh. In.
		5	55	"	III	Tr. In.
		7	01	"	III	Sh. Eg.
Nov.		7	12	A. M.	III	Tr. Eg.
		5	29	P. M.	I	Sh. In.
		5	35	"	I	Tr. In.
		7	42	"	I	Sh. Eg.
		7	46	"	I	Tr. Eg.
	15	4	56	"	I	Oc. Re.
	17	7	10	"	III	Ec. Dis.
		8	43	"	III	Ec. Re.
	18	2	42	A. M.	II	Oc. Dis.
		4	58	"	II	Oc. Re.
		6	27	"	I	Sh. In.
		6	27	"	I	Tr. In.
	19	3	37	"	I	Oc. Dis.
		5	48	"	I	Oc. Re.
		9	01	P. M.	II	Tr. In.
		9	04	"	II	Sh. In.
		11	17	"	II	Tr. Eg.
		11	25	"	II	Sh. Eg.
	20	12	53	A. M.	I	Tr. In.
		12	55	"	I	Sh. In.
		3	04	"	I	Tr. Eg.
		3	08	"	I	Sh. Eg.
		10	03	P. M.	I	Oc. Dis.
	21	12	17	A. M.	I	Ec. Re.
		6	14	P. M.	II	Ec. Re.
		7	19	"	I	Tr. In.
		7	24	"	I	Sh. In.
		9	30	"	I	Tr. Eg.
		9	36	"	I	Sh. Eg.
	22	4	28	"	I	Oc. Re.
		6	45	"	I	Ec. Re.
	24	10	34	"	III	Oc. Dis.
	25	12	44	A. M.	III	Ec. Re.
		4	55	"	II	Oc. Dis.
	26	11	17	P. M.	II	Tr. In.
		11	42	"	II	Sh. In.
	27	1	33	A. M.	II	Tr. Eg.
		2	03	"	II	Sh. Eg.
		2	35	"	I	Tr. In.
		2	50	"	I	Sh. In.
		4	47	"	I	Tr. Eg.
		5	02	"	I	Sh. Eg.
		11	47	P. M.	I	Oc. Dis.
	28	2	12	A. M.	I	Ec. Re.
		6	01	P. M.	II	Oc. Dis.
		8	50	"	II	Ec. Re.
		9	02	"	I	Tr. In.
		9	18	"	I	Sh. In.
		11	13	"	I	Tr. Eg.
		11	31	"	I	Sh. Eg.
	29	6	13	"	I	Oc. Dis.
		8	41	"	I	Ec. Re.
	30	5	39	"	I	Tr. Eg.
		5	59	"	I	Sh. Eg.

In. denotes ingress; Eg. egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow.

Configuration of Jupiter's Satellites at 10 p. m. Central Time.

Nov.		Nov.		Nov.	
1	4 3 ○ 2 1	11	1 ○ 2 3 4	21	4 3 1 ○ 2
2	4 2 3 1 ○	12	2 ○ 1 3 4	22	3 4 ○ 1 2
3	● 4 ○ 1 3	13	● 2 ○ 3 4	23	3 2 1 4 ○
4	4 1 ○ 2 3	14	3 1 ○ 2 4	24	● 2 ○ 1 4
5	4 2 ○ 3 ♃	15	3 ○ 4 1 2	25	1 ○ 2 3 4
6	2 4 ○ 3 1	16	3 4 2 1 ○	26	○ 2 1 3 4
7	3 1 ○ 4 2	17	4 2 ○ 3 1	27	2 1 ○ 3 4
8	3 ○ 2 1 4	18	4 1 ○ 2 3	28	♃ 3 ○ 2 4
9	2 3 1 ○ 4	19	♃ 4 ○ 1 3	29	3 ○ 1 2 4
10	2 ○ 3 1 4	20	4 2 ○ 3 ●	30	3 2 1 ○ 4

Phases and Aspects of the Moon.

		Central Time.	
	d	h m	
New Moon	Nov. 8	6 57	A. M.
Apogee	" 11	9 24	P. M.
First Quarter	" 16	11 45	A. M.
Full Moon	" 23	12 08	P. M.
Perigee	" 24	8 00	A. M.
Last Quarter	" 30	3 08	A. M.

Ephemeris of the Fifth Satellite of Jupiter.—We take the following ephemeris by Mr. Marth from the *Monthly Notices* for June, 1893, adapting it to convenient use in the United States. The period of the fifth satellite is assumed to be $11^h\ 57^m\ 21.88^s$, the uncertainty being, according to Mr. Marth, probably within a second of time.

APPROXIMATE TIMES OF GREATEST ELONGATION.

	Greenwich Time.		*Central Time.*	
	East.	West.	West.	East.
Oct. 5	11 44 P. M.	5 43 A. M.	11 43 P. M.	5 41 A. M.
9	11 22 "	5 21 "	11 21 "	5 20 "
13	11 00 "	4 59 "	10 59 "	4 58 "
17	10 38 "	4 37 "	10 37 "	4 35 "
21	10 15 "	4 14 "	10 14 "	4 13 "
25	9 53 "	3 52 "	9 52 "	3 51 "
29	9 31 "	3 30 "	9 30 "	3 29 "
Nov. 2	9 09 "	3 08 "	9 08 "	3 07 "
6	8 47 "	2 46 "	8 46 "	2 45 "
10	8 24 "	2 23 "	8 23 "	2 22 "
14	8 02 "	2 01 "	8 01 "	2 00 "
18	7 40 "	1 39 "	7 39 "	1 38 "
22	7 18 "	1 17 "	7 17 "	1 16 "
26	6 56 "	12 55 "	6 55 "	12 53 "
30	6 34 "	12 33 "	6 33 "	12 31 "

It will be seen from this ephemeris that the two months of October and November will be very favorable for observations of the satellite, for those who have sufficient optical means. As the times of the satellite's elongations occur at so nearly the same time each night, we have given them only for every fourth night. The others may easily be found by interpolation, the change being five and a third minutes per day. Of course no one will attempt to see this satellite unless he has a telescope of 15 inches or greater aperture.

COMET NOTES.

Discovery of Comet *b* 1893 in June.—Mr. W. E. Sperra of Randolph, O., was so fortunate as to observe the comet, commonly known as Rordame's, nearly three weeks before the discovery was announced. Curiously and unfortunately he mistook it for Finlay's comet, thus losing the credit of an important discovery, and depriving astronomers of a splendid opportunity to photograph the developing tail of the comet as it approached perihelion. The letter following this note gives his own account of the discovery and subsequent observations. Mr. A. G. Sivaslian has extended the ephemeris of the comet back to June 20, using elements III published in August ASTRONOMY AND ASTRO-PHYSICS. The following comparison shows a sufficiently close agreement between the ephemeris and Mr. Sperra's observations to prove the latter genuine.

					Observed				Computed		
		Gr. M. T.		R. A.		Decl.		R. A.		Decl.	
		h	m	h	m	°	′	h	m	′	°
June	19	20	25	2	43	+ 17	30	2	41	+ 17	42
	21	19	55	2	47	19	35	2	48	19	30
	22	20	25	2	50	20	30	2	51	20	30
	23	19	55	2	54	21	50	2	55	21	43
	25	20	25	3	05	24	30	3	05	24	28
	27	20	25	3	21	28	15	3	19	27	29
	29	20	25	3	37	31	10	3	37	31	08
July	1	20	25	4	03	36	05	4	04	35	50
	3	20	25	4	43	41	20	4	44	41	17
	5	20	25	5	36	45	25	5	37	45	25
	8	14	55	7	21	49	25	7	20	47	50
	9	14	55	8	00	48	50	7	59	47	57
	10	14	25	8	31	46	48	8	30	47	00

"I awaited the issue of the August number of ASTRONOMY AND ASTRO-PHYSICS with unusual interest. Permit me to say at once that had the journal appeared in July, or if I had had an ephemeris of Finlay's comet for the month of June, I would have had the honor of announcing the presence of Comet *b* 1893. But as it was I mistook it for comet Finlay, and had no intimation of my mistake, until I received the August number of Word and Works, a meteorological journal published by Ira R. Hicks of St. Louis, Mo. And then, I could scarcely believe that I was mistaken, and that it was a new comet. And so I awaited with unusual interest the August number of ASTRONOMY AND ASTRO-PHYSICS to settle the doubt. When it came, then the fact was revealed to me that I had discovered Comet *b*, 1893, two weeks, four days, and nineteen hours before it was seen by Alfred Rordame on the evening of July 8, 10 P. M.

My discovery of the said comet was on this wise: As above stated, having no ephemeris of Finlay's comet, I approximately extended the search ephemeris of this comet which was printed on page 469 of the May number of ASTRONOMY AND ASTRO-PHYSICS, for June 20, and on the morning of that day I was sweeping for it, a comet was picked up within 3^m of the approximately computed place, and which was supposed to be the comet in question. Its approximate position was found to be 2^h 43^m, R. A., and declination 17° 30′ north, for 3 A. M., local mean time, or 8:25 A. M. Greenwich mean time. It was of about the sixth magnitude or less, round, nebulous with condensation toward centre, perhaps 3′ in diameter. The next morning was cloudy and no observation was made. But the morning of the 22d was a favorable one; its position was then R. A. 2^h 47^m, and Decl. 19° 35′, although at the time its declination was recorded as 2° less than last given. This also served to make me fail to distinguish it from Finlay's. For the first three mornings I diagramed every star near the comet, and by this means was enabled to detect the mistake in Decl. On the morning of June 24, it was near ε Arietis. I enclose a diagram showing its apparent path among the stars, also a copy of my observations prior to July 10th. The observations are for local mean time; if Greenwich mean time is desired it will be necessary to add $5^h\ 25^m$, to the longitude of Randolph. From the diagram it will be noticed that it passed on June 30 within 2° of ζ Persei, and on July 4 near ζ Aurigæ, and on the 5th near Capella. The comet is shown in Diagram by circle, and which represents its place on morning of dates given at top of diagram. No tail was seen at any of the morning observations. The decrease in size and brightness on several mornings may be due to imperfections of the atmosphere which was foggy most of the time, and moonshine which rendered the sky white. It will be noticed that I have twelve recorded observations of the comet before its discovery on the P. M. of July 8. To make matters worse no newspaper notice of its discovery by Rordame came under my observation, that by this I might have received the hint of its being a new comet, but as it was, I had no hint until as described above. I pointed it out to visitors as comet Finlay, so certain was I that it was that comet. It was seen here at its best on Sunday evening, July 9."

W. E. SPERRA.

Randolph, Ohio, Aug. 7, 1893.

Observations of Comet *b* 1893.

1. June 20, 3 A. M. Picked up while sweeping for comet Finlay, which it was supposed to be. Magnitude 6 or 6½, nebulous with condensation toward center; round, no tail. R. A. $2^h\ 43^m$. Dec. 17° 30′ N.

2. June 22, 2:30 A. M. Seen with naked eye as a faint white spot of light. R. A. $2^h\ 47^m$. Dec. 19° 35′ N.

3. June 23, 3 A. M. R. A. $2^h\ 49½^m$. Dec. 20° 30′ N. Description same as above.

4. June 24, 2:30 A. M. R. A. $2^h\ 54^m$. Dec. 21° 50′ N. Diameter 4′ or 5′. 6 Mag.

5. June 26, 3 A. M. R. A. $3^h\ 5^m$. Dec. 24° 30′ N. Description same as above.

6. June 28, 3 A. M. R. A. $3^h\ 21^m$. Dec. 28° 15′ N. Description same as above except smaller in diameter and not so bright, may be owing to poor definition.

7. June 30, 3 A. M. R. A. $3^h\ 37^m$. Dec. 31° 10′ N. Description same as above.

8. July 1, 3 A. M. Position not taken. Magnitude 3½; diameter 6′; fair definition, Moon interference.

9. July 2, 3 A. M. R. A. $4^h\ 3^m$. Dec. 36° 5′ N. Description same as above; sky foggy.

10. July 4, 3 A. M. R. A. $4^h\ 43^m$. Dec. 41° 20′ N. Description same as above; too light and foggy.

11. July 6, 3 A. M. R. A. $5^h\ 36^m$. Dec. 45° 25′ N. Diameter 5′; no distinct nucleus, but dense toward center; 4 magnitude.

12. July 8, 3 A. M. No position taken as out of range of equatorial on account of trees. Near horizon and foggy. Comet appears somewhat dim, but presents same characteristics as in preceding.

13. July 8, 9:30 P. M. R. A. $7^h\ 21^m$. Dec. 49° 25′ N. Near horizon.

14. July 9, 9:30 P. M. R. A. $8^h\ 0^m$. Dec. 48° 50′ N., 3 magnitude; distinct nucleus and train gracefully curved toward Polaris, 15′ in length; coma about 9′ diameter; sky deep clear blue.

15. July 10, 9 P. M. R. A. $8^h\ 31^m$. Dec. 46° 48′ N. Description as above, except tail not so distinct and curved toward β Ursa Minor; the coma has also decreased in diameter, but may be owing to slightly foggy atmosphere.

P. S. My telescope with which the above observations were made is a two-inch objective. Power 36 dia.— W. E. SPERKA.

Randolph, Ohio.

Passage of Finlay's Comet through the Præsepe Cluster.—In *Astr. Nach.* 3187 Dr. Berberich calls attention to the fact that Finlay's comet will from Oct. 3 to Oct. 8 be passing through the Præsepe cluster of stars, and calculates the following table of times when the comet will be near individual stars of the cluster. We fear however that the comet will be too faint for any one to observe it.

Yarnall's Number	Conjunction in R. A. Paris M. T.		$\Delta\delta$
		h	′
5	Oct. 2	20.9	− 0.2
9	3	3.8	− 2.3
16	3	15.1	− 1.4
37	4	6.0	+ 0.3
59	4	21.1	− 0.6
69	5	2.2	− 1.0
74	5	± 3.0	+ 0.2
89	5	7.5	+ 1.0
134	6	8.8	0.0
148	7	12.7	− 1.4
150	7	17.0	+ 1.9

The Binary Star *OΣ* **82.**—Since its discovery this star has described an arc of 87°.4. Although the measures are not numerous, they are pretty exact, and it is now possible to determine the elements of the true orbit. The investigation will be printed in *Astronomische Nachrichten in extenso.* I give here the results obtained:

$$\begin{aligned} T &= 1945.0 \\ U &= 158.4 \text{ years} \\ n &= -2^\circ.2732 \\ \Omega &= 77^\circ.5 \\ \lambda &= 296^\circ.7 \\ i &= 43\ .8 \\ e &= 0.213 \\ a &= 0''.94 \end{aligned}$$

Position of the star for 1880:

$$\alpha = 4^h\ 15^m.9 \qquad \delta = +14^\circ\ 46'$$

Magnitudes of the components: 7 — 9.

These elements must be considered as the first approximation; their corrections can be obtained only when new observations will be made. Allow me to call the attention of astronomers possessing large telescopes to this system.

I will be glad to receive any unpublished observations.

By the last measures of Professor S. W. Burnham, we have the following for the relative positions of the components:

$$1892.00 \qquad \theta = 149^\circ.3 \qquad \rho = 0''.62$$

S. GLASENAPP.

St. Petersburg, Observatory of the University.

NEWS AND NOTES.

The delay in issuing the first number of *Popular Astronomy* was due to failure in photogravure work on four plates. We have promised good illustration in both magazines and we mean to have it, if it sometimes occasions delay.

The support indicated for *Popular Astronomy* so far is favorable. It seems as if there ought to be sufficient call for such a magazine if we can judge rightly from the indications of the last decade of years. We do not wish to publish a popular magazine of this kind unless it can be well enough supported to enable us to make it first class in every particular, as far as we have ability to do this. The number for October will be an improvement on the previous one, and will probably appear between the 10th and 15th of that month.

Nautical Almanac Office under Investigation.—In our last number we presented a brief report of an investigation of the conduct, by Professor Newcomb, of the Nautical Almanac Office at Washington, D. C. We are advised that Capt. McNair's report on the subject has been submitted to Secretary Herbert, but that his decision has been delayed on account of Professor Newcomb's absence on his summer vacation. Meanwhile its contents appear to be kept strictly secret. We are also advised that we were slightly in error in the statements of our last issue on some points affecting Dr. Morrison; yet, after looking over the various accounts of the trial received, a second time, it is not easy to see wherein we made wrong statements in the matter of fact at issue in our last number. Both Professor Newcomb and Dr. Morrison called for an investigation, grave charges being preferred on the one hand, and serious incompetency alleged on the other. The investigation was ordered promptly and the announcement of the decision only remains. Quite recently we have received considerable information about the specific charges referred to above, both in regard to the management of the Nautical Office and also respecting the ability of the assistants employed. It would be premature to refer to these points specifically pending the announcement of the results of the investigation. What ought to be said later that our readers may understand the merits of the case, as far as we can learn them, we will not fail to give. In our former note we did not mean to question Dr. Morrison's ability as a mathematician, for that would have been out of place at the time; but the manner of presenting his case seemed to us singularly unfortunate, the particulars of which we need not specify. We have held favorable opinions of Dr. Morrison's scholarship mainly because of his reputation and the favorable recommendations from the professors of the Naval Observatory, among others, submitted as evidence in the investigation, a fair example of which is the following testimonial:

"I have the pleasure of certifying that Dr. J. Morrison is the author of one of the best works on Trigonometry I know of in the English language; that he is a teacher of great ability and experience and complete master of all the branches of pure and applied mathematics taught in our best colleges. His ability as a mathematician and astronomer has gained for him not only a high position in this office, but also a wide reputation in this country and in Europe. During my absence for more than a year, he had charge of the mathematical work of this office, and at the same time rendered me valuable assistance in the preparation of my series of mathimatical text books. S. NEWCOMB.

"Nautical Almanac office, May 1, 1886."

A New Escapement for Astronomical Clocks.—At a meeting of the astronomical congress in Chicago, Professor Leman, of the Physical Technical Institute in Berlin, described a new form of clock escapement, which is said to give really wonderful results. Several clocks provided with this escapement are on exhibition in the gallery of the electricity building. The pendulums are also of novel construction, and with the escapement were invented and made by S. Riefler of Munich.

In these clocks, the pendulum is not suspended from a fixed support, but from a brass piece which has a slight rocking motion in the plane of vibration of the pendulum. The axis of rotation is a knife-edge, and it is practically coincident with the axis of the motion of the pendulum. The escapement rocks the support at each swing of the pendulum, so as to bend the spring slightly and give a sufficient impulse to keep up the motion. As the angle through which the support moves is constant, and the friction of unlocking is almost insensible, the pendulum may be considered as almost perfectly free.

The pendulum rod is a Mannesmann steel tube two-thirds of an inch in diameter, about two-thirds full of mercury. The bob is lenticular in shape, and made of bronze. It is not placed at the bottom of the rod, but at some distance from the lower end, the exact position being determined by computation. The coefficient of expansion of each rod is determined separately.

The advantages of this construction are an exact adjustment of the temperature compensation, the quickness with which the pendulum assumes the temperature of its surroundings, and the small effect on the rate of the clock of barometric changes.

The workmanship of the clocks in the exhibit is excellent. A remarkably small driving weight is required in every case.

Trials of one of these clocks at the Munich Observatory, extending over a little more than a year, showed that the rate was extremely uniform. Professor Seeliger regards the escapement and pendulum as constituting a distinct advance in the art of clock-making.

A New Royal Observatory for Edinburgh.—A new and handsome Observatory building is being erected on the Blackfoot Hills just outside of and overlooking the city of Edinburgh. This is to take the place of the old, antiquated and crowded Royal Observatory so long an ornament to Calton Hill.

Dr. Ralph Copeland, Scotland's astronomer Royal, is busily supervising the construction of the new buildings, and will at last have an Observatory worthy of his ability.

The fine instruments given to the Royal Observatory by Lord Crawford, and which were previously at his Observatory at Dun Echt. will be installed in the Observatory as soon as the buildings are completed, which wil perhaps be a year hence.

The new Observatory, besides containing one of the finest astronomical libraries, and various offices, will have at its ends two large cylindrical domes. In the largest of these will be placed the fine 15-inch refractor of Dun Echt. The smaller dome is to be occupied by the 24-inch reflector of the old Observatory, which Dr. Copeland hopes here to put to good use in measuring the lunar heat. The fine meridian circle of Dun Echt will be handsomely mounted in a detached building.

There are also to be handsome and comfortable residences for the Astronomer Royal and his assistants.

In the erection of this new building, the government has had an eye to beauty as well as to utility, and when finished it will be architecturally one of the handsomest observatories in existence. It is in the midst of a public park and cannot be crowded out by residences. It will be in full view of the city of Edinburgh and will doubtless be pointed to with pride by the inhabitants of that beautiful city. It is only a couple of miles distant, across the city, from the old Observatory.

The new Observatory is now about half finished and is built of a light-colored sandstone which is very durable.

Dr. Copeland, with an eye to a possible large refractor in the future, has made the domes amply large enough to accomodate a telescope comparable with the best now in use.

The present position of the Royal Observatory in the midst of Edinburgh's dust and smoke, has been a great drawback to delicate work. Dr. Copeland, however, says that there was never any trouble from vibrations from the city around and below, from which he thinks the rock composing Calton hill is not continuous.

Engraving in Knowledge.—The August number of *Knowledge* (London, 326 High Holborn, W. C.) contains a number of admirable photo-reproductions of some splendid Moon negatives made by the Henry Brothers of the Paris Observatory.

These pictures which are very sharp and clear were enlarged direct in the principal focus of the telescope. The magnifying power was fifteen times. These pictures illustrate a very interesting paper on the surface features of the Moon by Mr. A. C. Ranyard, the editor. This number of *Knowledge* also contains an excellent paper by Miss Agnes M. Clerke on the Sun as a bright line star.

Mr. Ranyard deserves great credit for the most excellent manner in which he presents to the public in *Knowledge, regardless of expense*, such admirable reproductions of the latest photographs of the celestial bodies. Many of these pictures would otherwise not be seen even by the average astronomer.

On a Wind Screen for Large Refractors.—In connection with the remarks that have lately appeared in ASTRONOMY AND ASTRO-PHYSICS about the necessity of a protecting screen in the observing slit of the 36-inch dome at the Lick Observatory, the following may not come amiss.

The importance of such a screen has been recognized at Nice and at Meudon. These observatories possess two of the largest refractors in Europe. The telescope at Nice has been in operation some years, while the great telescope at Meudon is just being erected under the supervision of M. Janssen.

At Nice it was found necessary to introduce some form of screen in the slit to shield the telescope from the wind. A system of canvas screens hinged to the inside of the slit and opening outwards by cords hanging down inside the dome, was found to work most effectually, and permitted the use of the telescope at times when it would otherwise have been impossible to use it on account of the wind.

At Meudon protection from the wind will be effected by a different form of screen, which has just been put in by M. Gauthier, who is mounting the great telescope. This is a canvas curtain working from the bottom of the observing slit on endless chains running up inside the dome on each side of the slit. It is easily and conveniently raised to any position by a rope. This is exactly the form of screen suggested by me as a wind guard for the slit of the 36-inch dome on Mt. Hamilton.

At Meudon it is a perfect success and will permit the use of the great telescopes at all times when the sky is clear. The device is simple and inexpensive and is indispensible in the use of large refractors.

It is altogether probable that such a screen will improve the definition, as it will prevent a disturbance of the atmosphere in the dome by wind currents.

Professor George Davidson has suggested (ASTRONOMY AND ASTRO-PHYSICS, 379) the substitution of a netting instead of canvas in making the screen. His great experience in observing in exposed and windy positions should give his suggestion great weight. I am myself not able to say just what effect a netting would have in stopping or rather in breaking the force of the wind. If it is effective, it is much to be prefered to canvas for the reasons suggested by Professor Davidson. E. E. BARNARD.

Alantic Ocean, Aug. 1. 1893.

A New Astronomical Observatory at Manila.—An important astronomical Observatory is soon to be established at Manila. Among other instruments it will contain a photographic meridian instrument of unique design, and a large refractor by Mertz.

Manila is in the Phillipine Islands in latitude about 14° north and differing some 180° in longitude from Washington.

The large telescope is to be the same size as those at Milan (Professor Schiaparelli's) and Strasburgh.

The object glass of this instrument, which is 19.2 English inches in diameter, is already finished by Mertz. The mounting is being made by [illegible] at Washington, and will be similar to that of the 12-inch at Washington, which was designed by Professor Harkness.

This telescope will also be provided with a photographic corrector, perhaps by Mertz.

Besides regular visual work, it is intended to use the instrument [illegible] photographic observations of the double stars, spectrographic work, [illegible] parallax, etc.

Father Algue, of the Georgetown Observatory, is at present in Europe and will bring back with him the large objective, and when the instrument [illegible] finished, he will proceed with it to Manila, where he will place it in [illegible] and begin work with it.

At present there is no astronomical Observatory at Manila. There is, however, a government meterological and seismographic Observatory [illegible]

Besides the establishment of this Observatory at Manila, Father [illegible] also undertake there a series of latitude observations in connection [illegible] similar series to be carried on by Fathers Hagen and Fargis [illegible] Observatory for the determination of the variation of latitude.

These observations (at both stations) will be made by these [illegible] They will extend over several years, begin about the last [illegible] of 1894. Talcott's Method by pairs of stars in the meridian [illegible] Though at both stations star trails will be used for the work [illegible] will differ considerably in principle.

They will both float in Mercury and will have a [illegible] only.

At Georgetown, the instrument with a sensitive [illegible] rected to the first star of the pair, and as the star crosses the meridian it will leave a trail on the plate. The instrument is then reversed and the other star allowed to trail on the same plate. The observation will consist in a combination of the circle readings and the measurement of the distance between the two trails.

As the stars cross the meridian the trails are broken by aid of the photochronograph indicating the points from which measurement must be made.

The corresponding instrument at Manila will consist essentially of two telescopes in the same tube—or at least there will be two object glasses one at each end of the tube, their foci coinciding. These will be of the same diameter and focus—the tube being equal to the sum of the focal lengths of the object glasses.

At the common focus of these lenses—in the middle of the tube— is placed a sensitive plate.

The telescope remains stationary throughout the observation of both stars. By the aid of the upper objective the first star trails on the upper side of the sensitive film. A basin of mercury now reflects the image of the second star up through the second object glass (in the lower end of the tube) where it trails on the underside of the same film—*through the plate*.

The objectives for these instruments are 6 inches in diameter and 3 feet focal length.

A Great Refractor for Dr. Janssen at Meudon.—A great refractor is just finished and placed in position for Dr. Janssen at Meudon.

It is a combined photographic and visual telescope. The two lenses were made by the celebrated Henry Brothers of the Paris Observatory.

The mounting is by Gauthier of Paris.

Both lenses will be mounted in the same tube which is *square* and of steel.

The visual objective is 82 c. m. (32 3 English inches) in diameter, while the photographic objective is 63 c. m. (24.8 English inches) diameter. Both lenses are of the same focal length, 17 meters (669 English inches).

The large objective will be the guiding part of the instrument when used for photography.

This great telescope is housed in the ruins of the old Royal Palace—a part of the ruins serving as the tower for the great dome, which dome is 20 meters (66 English feet) in diameter and weighs some 60 or 80 tons. The dome is to be moved by a gas engine of 12 horse power. The observing chair is attached to the dome and moves with it. All the fine circles are to be read from the eye end by means of electric lights, the electricity for which is generated by an 8 horse power engine half a mile distant in what was formerly the Royal Stables.

Professor Schaeberle's Theory of the Corona.—At the last meeting of the British Astronomical Association the late solar eclipse was the subject of some discussion by Professor Pickering, Mr. Taylor and others, who had taken part in the observations. We extract the following, with reference to Professor Schaeberle's theory of the corona, from the report of the meeting given in the English Mechanic of July 14.

"Capt. Noble, reverting to the matter of the eclipse, remarked that most of the members should be aware that Professor Schaeberle of the Lick Observatory, had a mechanical theory of the corona, and had made a sketch of what, according to his theory, the appearance of the corona would be at the time of the eclipse. He could not trace the slightest resemblance between this and the photograhps he had seen, and would like to ask Professor Pickering, Mr. Fowler and Mr. Taylor if their observations tended to confirm this.

Professor Pickering said that, as far as his observations went, they did not seem to agree at all with Professor Schaeberle's predictions.

Mr. Taylor had thoroughly examined his photographs, and could not trace the slightest resemblance. The most remarkable thing in them was the great extension at the pole. Mr. Wesley could trace this for two diameters. Professor Schaeberle showed on his drawing some short ones at the pole and a little at the equator.

Mr. Fowler said that he also had been unable to see any resemblance."

In Professor Schaeberle's note on page 693 will be found his answer to these and other similar criticisms.

Correction to the Article: On the Formation of Rings as a Process of Disintegration.—In my remarks about the formation of rings on page* 333, etc., of this year there is a lack of clearness if not quite an important error. The simple excess of attractive power of the main body over that of the satellite would not be evidently sufficient to carry away a free body from the latter as might have been easily inferred from my statements. The fact that the satellite describes a closed orbit about the main body proves, of itself, that the attraction of gravitation, as in the planetary system everywhere, exactly counterbalances the attractive power, because the whole satellite and each body upon it falls for the necessary amount towards the principal body. In regard to this read again what I wrote on page 335: "A free moving object on the surface of the new moon must instantly fly away from it towards Jupiter as soon as the latter rises above the horizon." By this, was expressed, although in a deplorably obscure way, the effect due to the difference of the attraction which the main body exerts upon the remotest and nearest points of the satellite, as a kind of tidal attraction. I have never thought an actual falling, or approaching of the loosened parts as occurring, for I later always, speak only of a ring at the distance of the satellite. The above mentioned reference further shows that I have assumed a rotation of the satellite around its axis which differs from the time of its revolution, because only in this way can the primary body rise and set for the satellite. This improbable assumption for so near a body further complicates the question, and doubtless I am to be blamed because I did not more thoroughly prove it mathematically. In the meantime this has been done in a thankworthy manner by Professors Schiaparelli and Seeliger and by our Dr. Schwahn. These researches in close agreement with one another, led to the result that a satellite whose diameter compared to that of the main body is small, and whose density is equal to it can not exist as such when its distance from the principal body is less than 2.1 semi-diameters of the latter. Now, since the new moon is distant from Jupiter 2.7 of his semi-diameters, the critical distance is not yet reached; consequently the moon cannot be disintegrated by the force of gravitation, although it is very near the limit of possible stability. On the contrary the rings of Saturn lie within the mentioned zone, and therefore the conclusions reached in this case in my article remain untouched. But as regards the dissolution of the moons, in the place in question, we would be obliged to depend on the small initial forces which might have been called forth at the time of separation by uneuqal temperature, expansive or explosive powers, or by disturbances of the other moons of Jupiter. In fact, if an exceedingly small force moves a free body on the surface of such a near moon in a tangential direc-

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* *Urania* probably. See Astronomy and Astro-Physics, May, 1893, page 407. —Editor.

tion in its plane of motion, it follows since the particle has only a very small gravity toward the satellite, that thus its motion away from the adjacent body must, under certain circumstances, go on continually, and that means that such particles must form a ring around the main planet. This process, moreover, may begin long before the satellite has reached the above mentioned critical distance.

We now recapitulate: A free body, on the satellite named in my first article, has, as there mentioned, under the suppositions made, no gravity towards the latter, but does not leave it, without some further causes, as there assumed. It must, moreover, at least, as long as its distance from the main planet is greater than 2.1 semi-diameters of the latter, possess an initial velocity which will drive it away from the surface. On the contrary, as just mentioned, if the distance is less, destruction will speedily follow through the attractive force of the main body. The new moon of Jupiter is only a small distance outside of the limit named.

If I had known earlier that this question might take such a complicated form, and what would have been my duty in respect to it, I would not have dared to publish the article in our journal, since it is not our custom to bring out hypothetical things until they have passed the judgment of the professional circle. Now, unfortunately nothing else is possible but to refer to it again.

M. WILHELM MEYER.

A Field for Woman's Work in Astronomy.—This is the title to a valuable paper beginning on page 683 of this number. It is due to Mrs. M. Fleming, the writer, to say that it was prepared for the "Woman's Branch" and was therefore addressed to women and not to astronomers. If she had supposed that it would be read in the Astronomical Congress the language of some parts of it, she says, would have been changed. On account of Mrs. Fleming's wish this reference to the article is made, although we had in no way regarded the apt and direct language of it, as at all inappropriate for the welcome place accorded the paper in the Astronomical Congress at Chicago.

Astronomical and Physical Society of Toronto.—We are sorry to say that after vacation months we are taxed to give all the interesting matter in hand space. The reports of late meetings of the Astronomical and Physical Society of Toronto are full of useful and interesting matter and deserve place in this number, but we have had to pass them with several excellent articles that are waiting our next issue.

On a Recent Theory of Ring Formation.—In the May number of this Journal, there appeared an article on "The Formation of Rings as a Process of Disintegration," by Dr. M. Wilhelm Meyer. In the article referred to, the author endeavors to show that in the case of the fifth satellite of Jupiter, there is a tendency of all loose fragments of matter to fly off towards its great primary, whenever the latter has risen above the horizon to such fragments, by reason of the preponderance of the attractive force of Jupiter over that of the satellite, as measured at the surface of the latter. He further states that both of the satellites of Mars, the first satellite of Jupiter, the first three satellites of Saturn and the first two satellites of Uranus are in the same situation in this respect. In this brief article I merely wish to call attention to the fact that the author, in discussing the question as to the effect of the planet's attraction on loose objects situated on the surface of the satellite, has neglected to take into account the effect of centrifugal force, due to the satellite's orbital motion. If we denote the planet's attractive force, as exerted at the surface of the satellite, by G the centrifugal force resulting from the satellite's orbital motion by F, and the attractive force due to the mass of the satellite by g, then there will be a tendency for loose fragments to fly off, or to leave the surface of the satellite, only when $g < G - F$. It is hardly necessary to state that such a condition does not exist in the case of any of the known satellites of the solar system. If we suppose the diameter of the fifth satellite of Jupiter to be 100 miles, and its density to be equal to the surface density of the Earth, or say one-half of the Earth's mean density, as it is likely to be, approximately, and its distance from Jupiter's center to be 112000 miles, then for a particle situated on the surface of the satellite, with Jupiter in its zenith, we shall have $g = 17 (G - F)$, if we suppose the satellite to be without rotative motion. $G - F$ represents, in this case, simply the difference between the attractive force of Jupiter as exerted at that point on the surface of the satellite which is nearest to him, and that exerted by the planet at the center of the satellite. In order that there should be a tendency, in the case of this satellite, for detached fragments of matter to fly off, its density would have to be less than the one-seventeenth part of the Earth's surface density, or less than 0.16 the density of water.

This oversight of the author, here pointed out, was noticed on my first reading the article referred to in the May number of this journal, but thinking that some one else, or perhaps the author himself, would notice and call attention to it, I deferred doing so myself till now. It is almost needless to state that when the proper corrections are made in Dr. Meyer's computations, it will be seen that there will be no tendency to the formation of rings in the manner he indicated.

ROBERT HOOKE.

Jupiter's Comet Family.—In the first number of *Popular Astronomy* some errors seemed unavoidable. The errors of names in the plate could not be corrected because engravers were much behind time. Several members of the family also were not given. Another plate will be given soon which will correct these obvious errors. A list of the elements of orbits of these comets will accompany the new plate.

BOOK NOTICE.

The Planet Venus. A short summary of the present knowledge of the planet, by Ellen M. Clerke. Publishers *Knowledge*, office London, pp. 61.

This little monograph is a worthy companion to its predecessor of last year, Jupiter and His System, and is intended to fill a similar place. There is an introductory chapter of much interest on Venus as the Hesperus and Phosphor of the Greeks, while the last chapter discusses her claims to being the star of Bethlehem. The intermediate pages are filled with a lucid description of the various phenomena to be observed, and a careful discussion of the vexed questions of the planet's period of rotation and the existence of a satellite.

Were the author unknown we should never suspect that the severely plain style in which Jupiter is described and the graceful imagery with which the story of Venus has been clothed could have a common origin. For they are as different as the cold majesty of the one with his court of satellites, and the simple beauty of the other. There will always be a place for such publications which, while laying no claim to exalted merit, still from the heterogeneous mass of observations good, bad and indifferent select the salient points and arrange them in logical and readable form. Its publication is especially well-timed, since Venus as evening star will receive much attention in the next three months from astronomers professional and amateur.

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Astronomy and Astro-Physics.

VOL. XII, No. 9. NOVEMBER, 1893. WHOLE No. 119.

General Astronomy.

ON THE ATMOSPHERIC REFRACTION AT MADISON, WIS.*

GEORGE C. COMSTOCK.

Investigations of the atmospheric refraction may be divided into two classes, one of which may be regarded as a department of theoretical physics, consisting of the mathematical investigation of the path of a ray of light traversing a gaseous medium of varying density, and resulting in an expression for the curve of the ray in terms of certain arbitrary constants. The other class of investigations is concerned with the experimental determination of the values of these constants, or, more precisely, in determining for the constants a set of values which will render as consistent as possible among themselves the observations made with a given instrument.

There seems to be no physical reason why such quantities as the index of refraction and co-efficient of expansion of air should not be the same in all parts of the Earth, when due allowance is made for such variable elements as temperature, gravity, etc., but the investigations of the second class, made at Greenwich, Paris, Königsberg, Pulkowa, etc., furnish quite different values of these quantities, and indicate as a probable conclusion that a certain amount of undetermined instrumental error has gone into them. While there can be no doubt that in the particular cases for which these investigations were made the erroneous values thus deduced have furnished a better system of reductions for the observations than could have been derived from correct values of the constants, this masking of instrumental errors renders the resulting refraction tables ill adapted to use under other circumstances or at other places; and imposes upon every observatory at which absolute declinations are observed the duty of redetermining for its own surroundings another set of values for these constants which shall so far as possible eliminate its own peculiar errors.

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* Read at the Congress of ASTRONOMY AND ASTRO-PHYSICS, Chicago, August, 1893.

I have made such an investigation for the meridian circle of the Washburn Observatory, from the best data accessible, following the classic method of determining the latitude from observations of stars at different distances from the pole, observed at both upper and lower culminations. These observations were reduced with the so-called Pulkowa Refraction Tables, which are constructed from Gyldèn's theory with two arbitrary constants deduced from observations with the Pulkowa vertical circle. Although theory indicates several minute corrections which should be applied to these tables in order to transform their data to the latitude of Madison, *e. g.*, those due to gravity, curvature of the meridian, humidity, etc., these corrections were neglected and the observations reduced with the tables unchanged. I have grouped the latitude results thus derived in accordance with the north polar distance of the stars employed, determining the limits of the zones, so that the partial results shall have equal weight. The several results, for the seconds of this latitude together with the results which would have been derived had Bessel's refractions been employed in the reductions, are shown in the following table:—

N.P.D.	Z.D.	Gyldèn.	Bessell.
1° - 8°	51°	36″.72	36″.54
10 - 13	58	36 .69	36 .50
14 - 19	63	36 .69	36 .48
19 - 24	68	36 .74	36 .51
24 - 31	74	36 .72	36 .45

The column headed Z.D. shows the average zenith distance of the stars observed below the pole. The observations were not arranged with reference to an investigation of the refraction and do not extend beyond 78° zenith distance.

The two refraction tables employed furnish appreciably different values of the latitude, but each of them produces an agreement among the individual results quite as great as could be expected from the probable errors of the data, and either table may therefore be employed for the derivation of a latitude with this instrument, its low latitude causing the different values of the constants employed in the tables to produce sensibly the same effect upon results from stars at different distances from the pole; but the two refraction tables will furnish quite different results for the declinations of southern stars *e. g.*, Bessel's refraction would place a star in — 30° declination 0″.7 further south than Gylden's, and the method ordinarily employed for an investigation of the refraction is unable to decide which system should be employed.

I have therefore resorted to another method for an investigation of the refraction,—the measurement of the angular distance between stars widely separated in the heavens. The instrument employed for this purpose is a modified form of the Loewy prism apparatus, attached to the six-inch Clark equatorial telescope of the Washburn Observatory. The principal element of the apparatus is a system of mirrors so placed before the objective as to reflect into the telescope images of the stars which are to be observed, both images being simultaneously visible, as in the case of sextant observations. In fact the apparatus may be regarded as a reflecting instrument employed like a sextant, but whose attainable precision bears about the same relation to the precision of sextant observations that its six-inch objective bears to the objective of a sextant telescope.

It is not my purpose to discuss here the theory of the instrument or its errors, and the methods employed for eliminating these defects, further than to say that these have been elaborately investigated, and that after all known sources of error had been taken into account, the measured distances between pairs of stars were compared with distances computed from the stars' cöordinates, right ascension and declination, and a system of very minute corrections arising from personal errors of the observer was determined whose application to the measured distances brought them into agreement with the mean of all the computed distances. All of the 76 stars observed are situated near the equator, and errors in their adopted declinations, therefore, have an exceedingly minute effect upon the computed distances, and as for errors in the adopted right ascensions, it is obvious that an error of equinox has no effect whatever upon the distance between a pair of stars, and that the effect upon the final results of all systematic error in the right ascensions is eliminated by the distribution of the stars throughout the twenty-four hours of right ascension. The mean of the computed distances can therefore be affected only by an accumulation of accidental errors, and as all of the stars have well determined places, the effect of these errors must be exceedingly small. Nevertheless even this residual effect has been in great part eliminated, by the observation of groups of stars making the complete circuit of the heavens.

The theory upon which the investigation of the refraction proceeds is exceedingly simple. The atmosphere constitutes a hollow sphere which bends every ray of light entering it obliquely, and diminishes the angular distance between every pair of stars above the horizon. The analytical expression for this effect of the refraction in terms of the ordinary refraction theory is comparatively simple, and equating this expression to the difference between the measured and computed distances separating the stars, we obtain a series of equations from which the constants of the refraction theory may be derived.

The available data of this kind are 812 observations of the distances between 38 pairs of stars. All of these observations were made when the stars comprising a pair were at approximately equal distances from the zenith, and these zenith distances ranged from 64° to 73°. All of the investigation and all of its results, therefore, relate to zenith distances included within these limits, and the conclusions here presented are not definitive, since the right ascensions of a few of the stars are still under investigation.

There are some subsidiary matters which it will be necessary to consider before proceeding to the absolute values of the constants with which this investigation is chiefly concerned, and chief among these is the possible effect of humidity of the atmosphere upon the refraction.

The only investigation known to me of the effect upon the refraction of the presence of aqueous vapor in the atmosphere is that of Laplace contained in the Mécanique Céleste. Laplace derives numerical values for the effect of humidity, and after tabulating them remarks: "*Il resulte de cette table que l'effet de l'humidité de l'air sur la refraction est tres-peu sensible, l'exces de la puissance refractive de la vapeur aqueuse sur celle de l'air étant compensé en grande partie par sa plus pétite densité.*" *Méc. Cél., Vol. IV, Book V, Chapter 1.* This remark of Laplace's seems to be at least partially justified by an investigation of C. A. F. Peters, who found that observations of Polaris with the Pulkowa vertical circle, when made through clouds, furnished a latitude 0″.04 greater than that derived from observations made in a clear sky. Recueil de Mémoires, etc., par W. Struve, Vol. I, p. 142.

I know no other foundation than the above for the common practice of assuming the effect of humidity upon the refraction to be insensible, and the evidence thus adduced seems open to the following criticism: The observations of Peters which were made through clouds were distributed throughout the year, and their effect upon the latitude was discussed without any reference to the temperature at which they were made. It is apparent that the effect of humidity will be most pronounced at high temperatures, and during the winter months will have but a small fraction of the maximum effect which it attains in the summer. Peters' discussion, therefore, seems little adapted to bring out the real effect of the humidity, and in justice to him it should be stated that he does not appear to have intended to investigate this effect, since he expressly states: "*Il faut voir si les nuages, surtout par leur influence sur les temperatures de l'air, ne tendent pas à changer les refractions,*" etc.

As for the investigation of Laplace, it is based upon the theoretical physics of his day, and involves assumptions which are not tenable at the present time. In particular, his value of the index of refraction of aqueous vapor is derived from the index of refraction of water by means of the assumed relation

$$n^2 - 1/d = c$$

where c is a constant, n denotes the index of refraction and d the density of water, whether in the liquid or the gaseous state. The equation is a direct consequence of the emission theory of light, and although a certain amount of countenance is given to it by the undulatory theory, it is not necessarily involved in the latter and the experiments of Gladstone, Dale, and others, discredit it. In particular it should be noted that the equation in the hands of Laplace furnishes for aqueous vapor a refractive power greater than that of air, while laboratory experiments furnish a smaller value for its index of refraction. Thus the *Annuaire du Bureau des Longitudes* for the year 1892 gives, upon the authority of Mascart, the value 1.000257, while in Mascart's *Traité d'Optique* the value is given as 1.0002574, and attributed to Fizeau. The index of refraction of dry air is given by Mascart as 1.0002945. From the standpoint of modern physics, therefore, the refraction should be less in a humid than in a dry atmosphere, while Laplace's corrections tend in the opposite direction.

To determine the effect of the aqueous vapor corresponding to the numerical values above given, I denote by n_1 and n_2 the indices of refraction of air and aqueous vapor respectively at a temperature of t_0, C., and pressure of 760 *mm*, and denote the respective co-efficients of expansion by m_1 and m_2. The refraction corresponding to any zenith distance z is then given by the equation

$$R = \frac{n_1 - 1}{\sin 1''} \cdot \frac{b_1}{760} \cdot \frac{1 + m\,t}{1 + m_1 t} \tan z + \frac{n_2 - 1}{\sin 1''} \cdot \frac{b_2}{760} \cdot \frac{1 + m_2 t_0}{1 + m_2 t} \tan z$$

in which the two terms of the second member represent respectively the refractions produced by the air and by the aqueous vapor at pressures of b_1 and b_2 *mm* respectively.

The co-efficient

$$\frac{n_1 - 1}{\sin 1''}$$

is commonly called the constant of refraction, although it is slightly variable with the zenith distance, and

$$\frac{n_2 - 1}{\sin 1''}$$

should in strictness also be considered variable, but since it is multiplied by the small factor

$$\frac{b_2}{760}$$

its variations will be neglected, and the variation of the first co-efficient will be assumed known from the ordinary refraction theory. Let b represent the total atmospheric pressure

$$b = b_1 + b_2$$

and we have

$$R = \alpha \frac{b}{760} \cdot \frac{1 + m_1 t_0}{1 + m_1 t} \tan z$$
$$- \frac{b_2}{760} \left\{ \frac{n_1 - 1}{\sin 1''} \cdot \frac{1 + m_1 t_0}{1 + m_1 t} - \frac{n_2 - 1}{\sin 1''} \cdot \frac{1 + m_2 t_0}{1 + m_2 t} \right\} \tan z.$$

The first term in the second member of the equation is the ordinary expression for the refraction; the second term constitutes a correction to the refraction which may be represented by $\varDelta R$. To express this term in a simpler form let us put

$$\frac{(n_1 - 1)(1 + m_1 t_0)}{\sin 1''} = \mu_1 - 1 \qquad \frac{(n_2 - 1)(1 + m_2 t_0)}{\sin 1''} = \mu_2 - 1$$

$$\mu_1 - \mu_2 = \omega \qquad (\mu_1 - 1) m_2 - (\mu_2 - 1) m_1 = \psi$$

and obtain

$$\varDelta R = - \frac{b_2}{760} (\omega + \psi t) \tan z$$

To derive numerical values for ω and ψ I adopt the following values of the refractive indices and co-efficients of expansion of air and aqueous vapor

$n_1 = 1.0002945$	Biot et Arago.
$n_2 = 1.0002574$	Mascart, Fizeau.
$m_1 = 0.003670$	Regnault.
$m_2 = 0.004187$	Hirn.

and find after dividing by 760

$$\varDelta R = - b_2 \left\{ [8.0032 - 10] + [5.0273 - 10] t \right\} \tan z$$

the square brackets denoting that the numbers placed within them are logarithms.

By means of this expression the effect of the humidity at any zenith distance may be computed, and a comparison of observations made at high temperatures, but under different humidities, will suffice to test the reality of the correction. I have made such a comparison as follows: From the observations with the prism apparatus I have selected all those which satisfy the following conditions: The same pair of stars must have been observed at a temperature above 15° C., when the relative humidity was (a) greater than 80, (b) less than 60. Designating the observations (a) by the symbol W (wet) and the observations (b) by D (dry) I have formed for each pair of stars the mean difference W — D. There are in all 70 observations of 15 pairs of stars available for this comparison, and from these I find

$$\begin{array}{ll} \text{Uncorrected} & W - D = +0''.17 \pm 0''.08 \\ \text{Corrected} & W - D = -0\ .03 \pm 0\ .06 \end{array}$$

Although the quantities involved are small there seems to be little doubt that the effect of the humidity is sensible, and that it is correctly represented by the adopted formula. I have therefore applied this correction to all of the observations, and in what follows they are therefore to be considered as observations made in dry air.

The general character of the effect of humidity upon observations of zenith distance, reduced in the ordinary manner, may be shown as follows: The aqueous vapor tension of a saturated atmosphere within the range of temperature with which we are concerned may be represented by an exponential function of the temperature, and since the mean value of the relative humidity is nearly constant at all seasons we may write approximately

$$b_2 = \lambda 10^{\mu t} \qquad R = (\alpha\beta\gamma - f\lambda 10^{\mu t})\tan z$$

The numerical value of λ varies with the climate, being greater near the sea than in the heart of a continent. For Madison, where the average relative humidity is 75 per cent we have when t is expressed in degrees C.

$$\lambda = 0''.03 \qquad \mu = 0.030$$

It is evident that at low temperatures the effect of humidity will be quite small, but that it increases very rapidly with rising temperatures. The effect of this correction term is in part taken into account in the Pulkowa refraction tables by employing an erroneous co-efficient of expansion of air somewhat greater than the true value, but in Bessel's tables too small a value of this co-efficient is adopted, and the humidity effect, instead of being reduced, is considerably magnified in these tables. Bessel in fact appears to have been misled by Laplace into supposing that the effect of humidity was to increase the refraction, and that the coefficient of expansion which he determined from his observations ought therefor to be smaller than the true value for dry air, since he says in explanation of its difference from the value found by Regnault that it "*medio cuidam humorisstatui respondet.*" *Tab. Reg.*, *p. LX.*

By means of the two constants involved in α and γ of the refraction formula, the computed refractions may be made to agree with observation at any two temperatures, but if the humidity term be neglected they cannot agree at more than two points of the temperature scale, but will be too small at intermediate, and too great at extreme temperatures. It follows therefore that zenith distances reduced with the ordinary refraction tables should show a periodic variation running through its cycle in a period of a year. In the case of the Pulkowà tables the amplitude of this variation scarcely exceeds $0''.01$, but for the Bessel tables its amount is approximately $0.''07 \tan z$.

To exhibit the effect upon the refraction of the fluctuations in the humidity which take place from day to day I assume a zenith distance of 75° and a temperature of 21° C., and compute the humidity correction on two hypotheses, (a) that the α and γ of the refraction formula are derived for dry air, and represent the best attainable values of the physical constants involved; (b) that the α and γ are so derived from observation that they exactly represent the refraction at the given temperature for a mean condition as regards humidity. The results are as follows:

Relative Humidity.	50	60	70	80	90	100
ΔR (*a*)	$-0''.36$	$-0''.43$	$-0''.50$	$-0''.57$	$-0''.64$	$-0''.71$
ΔR (*b*)	$+0\ .18$	$+0\ .11$	$+0\ .04$	$-0\ .03$	$-0\ .10$	$-0\ .17$

These series of numbers may be considered as representing extremes between which the actual correction for a similar case may be expected to lie, and they lead to the conclusion that the humidity cannot safely be neglected in the refraction computations if it is desired to take tenths of a second into account.

The expression above given for ΔR may be transformed by means of the development of $\log(1-x)$ into a form much better adapted to computation with the ordinary tables. The result of this transformation is as follows: Let there be substituted for the γ of the tables the expression

$$\log \gamma = \log G + \log H$$

where G is the old γ recomputed with the co-efficient of expansion for dry air, and H is a function of the aqueous vapor pressure, b_2 *mm*, given in units of the fifth decimal place by the equation

$$\log H = -8.2\, b_2$$

The refraction computed with this value of γ will be substantially the same value that would have been obtained by the subtraction of ΔR.

Having corrected for humidity the observations made with the reflecting apparatus, it became necessary to derive a new value of the co-efficient of expansion of air, which was done by a comparison of distances of the same pair of stars observed at high and low temperatures. This determination is complicated by the necessity for taking into account the effect of changing temperature upon the instrument as well as upon the atmosphere, but fortunately the observations are sufficient to separate well these effects. The data available for the determination consist of 208 observations equally distributed between high and low temperatures, the average difference of temperature being about 15° C. I have not employed the method of least squares for the discussion of these data, but have grouped the equations resulting from the several observations in such a way as to eliminate the absolute distances between the stars and to produce maximum co-efficients for the correction to the co-efficient of expansion adopted in the Pulkowa tables. The resulting normal equations are

$$\begin{aligned} 43.33x - 6.88y &= +14''.42 \\ 3.13x + 33.92y &= +14.72 \end{aligned}$$

where x relates to the effect of temperature upon the atmosphere, and y to the corresponding effect upon the instrument.

The relation of x to the co-efficient of expansion of air is as follows: The temperature determinations which accompanied the observations were made by whirling a thermometer in the open air just outside the dome containing the instrument. Suspecting that although the errors of the thermometers were well determined, these observed temperatures might be affected by some error depending upon the mode of exposure, I carried on a simultaneous series of readings of thermometers placed in a closed chamber near the objective of the telescope, and ventilated by an exhaust fan which drew a gentle current of air from outside the chamber over the bulbs of the thermometers. The apparatus is substantially the same as Assman's Aspirations-Psychrometer, although I knew nothing of this instrument at the time of its construction, and while its indications may not be absolutely free from error, they appear to me far more reliable than any temperature determinations made with an exposed thermometer, and I adopt its indications as a normal system of temperatures. From a least square solution of the comparisons made between the ventilated and whirled thermometers I obtain the relation

$$V - W = + 0^\circ.015\ (t - 17^\circ) \text{ Centigrade,}$$

i. e., the true temperature may be represented as a linear function of the readings, W, of the whirled thermometer. Putting $t = \alpha + \beta W$ and denoting by m^1 the co-efficient of expansion of air adopted for the γ factor of the Pulkowa tables, and by m the corresponding co-efficient to be determined from the observations, we have

$$x = 10000(m\beta - m^1)$$

and from this equation, with the value of β experimentally determined, I find

$$m = 0.003674 \pm 8$$

the probable error including the uncertainty in the determination of β as well as x. The close agreement of this value of m with Regnault's classical determination 0.003670 furnishes a partial proof of the substantial accuracy of the several elements which have gone into its determination, and confirms the correctness of the temperatures furnished by the ventilating apparatus.

The values of x and y derived from the normal equations have furnished a set of corrections to the observed distances between pairs of stars by application of which these distances have been reduced to what would have been obtained had the observations been properly corrected for the effect of temperature upon the instrument, and reduced with the above value of m, or with substantially Regnault's value of m, since the difference between the two in no case produces a difference as great as $0''.1$ in the distances.

The observations thus corrected furnish a body of data which I have compared with the Pulkowa tables, corrected for the difference in gravity at Pulkowa and Madison by the subtraction of 0.00064 from log μ. The result of that comparison is that after the Pulkowa refractions have been corrected for gravity, for humidity, and for the changed value of m they require a further correction of + 0.00033 to log μ, or the refraction at 45° zenith distance should be increased $0''.04$. If the humidity correction be neglected, and the temperature factor of the tables retained unchanged, the correction to log μ will be a variable quantity whose average value is approximately $-$ 0.00025. The difference between Bessel's α and the μ of the Pulkowa tables is not constant, but its average value within the present limits of zenith distance is $\log \alpha - \log \mu = + 0.00115$, and the corrections to log α are therefore $-$ 0.00082, when the humidity and temperature corrections are applied as above, and $-$0.00140 when they are neglected.

The degree of confidence to be accorded these results depends upon the judgment that is formed with regard to the precision of the observations. The results derived for the effect of humidity and for the co-efficient of expansion of air being in close accord with the results of laboratory experiments, conducted under a much wider variation of conditions than can be attained in astronomical observations, tend strongly to show the freedom of the observations from any considerable systematic error, save possibly a constant error affecting all of the observations of a pair alike. The agreement among the results furnished by the separate pairs of stars is shown by the small probable error of the correction to the co-efficient of expansion of air, and farther by the probable error of a single observation, ± 0″.31, which is less than the probable error assigned by Bessel and Gyldèn to the computed refractions corresponding to the zenith distances at which the observations were made.

The above presentation is to be considered as a partial abstract of results. The observations together with a description and theory of the apparatus employed will be set forth in detail in the Publications of the Wàshburn Observatory.

PHOTOGRAPHIC OBSERVATION OF MINOR PLANETS.*

MAX WOLF.

The difficulty in finding a faint minor planet in order to get an observation of it, is a great one, because the position of the planet is usually but roughly known. Even with a good ephemeris it is often a very fatiguing work in consequence of the want of charts for the fainter stars. The observer must make a diagram of the region in which he supposes the planet to be. After

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* Read at the Congress of Astronomy and Astro Physics, Chicago, August, 1893.

a time, on comparing the diagram star by star with the sky, he finds that one star—the planet sought for—has moved. But if the ephemeris was very far from the true one, the whole work would be lost, because one would have taken up a false part of the sky.

A much greater work is to be done, if one wishes to detect a *new* minor planet. There are a hundred and more fields of view to be charted and compared, before a new one is found. The perseverance of the planet-hunter can not enough be admired.

Photography holds out—as will immediately be seen—two great advantages over this ancient method; first, it gives us a larger field and thus increases the probability of catching a planet about fifty times; then it permits us to distinguish the planet from the enormous number of faint stars, the planet moving amongst the stars and marking a short trail on the photograph.

I commenced photographing asteriods in 1890 using two instruments, a telescope lens of 16.2 cm. aperture and 262 cm. focal length, and an aplanatic lens of 6 cm. aperture and 44 cm. focal length. But I had no success, because I did not employ suitable lenses. The focal length of the first employed being too long, and the aperture of the second, too small.

(*a*). To photograph *faint* minor planets, a marked brightness of image is required.

For photographing nebulæ the brightness of image has as a factor approximately the quantity $\frac{D^2}{F^2}$, because the brightness of the image is diminished if the area is enlarged.*

A minor planet gives as area a "point." Comparing different lenses the brightness of the image would be in proportion to the square of the diameter: D^2, or more accurately in proportion to $\frac{D}{\sqrt{F}}$. But because the train of thought is the same for the two formulæ, we take for simplicity's sake the first.

The planet is moving during the time of exposure. Pointing the plate upon the fixed stars, we get a trail on the plate from the planet; and this trail becomes longer, when using a lens of longer focus. The intensity of the planetary image therefore is diminished by a longer focus, and we have approximately for the intensity: D^2/F (or perhaps more correctly, $D/F^{\frac{3}{2}}$).

To photograph minor planets, then, we need a lens with an

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* Where D is the diameter and F the focal length of the instrument.

aperture as great as possible, with a focal length as short as possible, and last but not least one giving a large field.

Mr. Roberts who has first photographed the minor planet Sappho, used his mirror of 51 cm. aperture and 254 cm. focal length. The intensity of his instrument was therefore 10.2. My first instruments gave an intensity only of 1.0 and 0.8, and therefore I had no success for fainter planets.

From this point of view, after having comprehended the matter I re-commenced the photography of minor planets in November, 1891, using an aplanatic lens, which had $T = 2.2$, which is still four and a half times feebler than Mr. Robert's. But it was strong enough and had a field twenty-five times larger than that of Mr. Roberts.

By this lens I got the first *new* minor planets discovered by means of photography. Subsequently I used a 6-inch portrait-lens. The intensity of which was 3.5, and the field about 100 square degrees.

A large portrait lens is the most efficient because D^2/F is there at a maximum and the field is also as large as possible. Reflectors therefore, are not useful in photographing minor planets, since their field is too small.

(*b*) To have success in photographing minor planets there are some other points on which care must be taken.

Very sensitive plates must be used. The development is to be made without haze; they must remain as clear as water. If not, the faint planetary trails are lost. For this reason moonshine is a very great impediment.

Photographic operations have to be finished as quickly as possible, in order that the examination of plates take place before the planet has moved too far.

There are a large number of objects on the plate which are similar to a planetary trail as close double stars, lines of nebulæ, and especially those faint stars, which are so remarkably pressed into laces. From *one plate alone*, therefore, the certain detection of a planet is seldom possible.

In order to ensure complete success, we take a second plate immediately after the first. Then every planetary trail is recognized by the rule that the trail on the second plate must be the continuation of the trail on the first plate, and that the spot where the planet was trailing on the first plate must be clear on the second, and *vice versa*.

Another way is the following: We use two similar pieces of apparatus, mounted together. With the one we expose a plate for the first and second hour; with the other for the second and third hours. In this way we need only three hours, instead of more than four by the first method.

(*c*). To take accurate positions from the plate there are several ways: for example by rectangular coördinates or by the parallactic apparatus, etc. I used my own method, because I was compelled to use the cheapest apparatus. I measure in the field of view of a microscope by a filar-micrometer the distances of the middle of the planetary trail from three or more comparison stars. From those distances I obtain by the formulæ of trigonometry the differences of α and δ.

Since a number of comparison stars can be taken, the position is less influenced by erroneous positions of comparison stars, than in ordinary optical work; and likewise errors of measuring and reckoning are checked by taking several stars, which is easily to be done in day-time.

(*d*). The question may now arise why we use the photographic method for position work—and not for planet-seeking only.

Indeed so far as regards my small portrait lenses—also Mr. Charlois'—the operation of measuring a planet, *of which* the *place is given*, is for the most part much more conveniently done by optical work with a large telescope, because the long fatiguing exposure is not required. But increase the photographic lenses by a few inches, and they will photograph planets invisible even through a large telescope. It has already often happened, that one of the smallest planets obtained by photography was below the optical power of a 12-inch Clark refractor.

If we can use larger portrait lenses, then we *must always* measure the positions by means of photography.

(*e*). There are some problems to be examined, which are connected with the measurement of the planetary trails, one o which I shall indicate.

In measuring the position of a planet on a plate, the sho trail must be bisected. Now it would appear that the time o the middle of the exposure is that of the middle of the tra But this is not necessarily true. The chemical process and th variation of the clearness of the sky can displace the middle the trail.

It is possible that from chemical reasons the trail is prolong a little at the end of the exposure. The simplest way to find was simultaneous eye-observations and photographs. But I h not the optical means to do so. I commenced to compare trails and points of a star cluster taken on the same plate. This very small prolongation, if it is there, must be easily found as a function of the velocity of movement and of the brightness of the star.

The second error is more troublesome. Even if we suppose, that the status of the atmosphere would remain the same during the exposure,—the influence of the absorption will displace the middle of the trail. For, if we expose upon a planet rising to its culmination, its impression upon the plate will first be very faint—perhaps too faint for any impression,—and towards the end, stronger and stronger, and then still further enlarged by the phenomenon of so-called photographic irradiation. Bisecting the resulting trail by our micrometer wire, we get a place, which belongs to a later time than the middle of the exposure.

Since it is only a question of time, when nearly all observations of faint minor planets will be made by photography, it is very desirable, that such problems are given our careful attention.

CHICAGO, August, 1893.

THE BUREAU OF MEASUREMENTS OF THE PARIS OBSERVATORY.*

DOROTHEA KHEMPKE.

Under the presidency of Rear-Admiral Mouchez, the International Astro-Photographic Congress was held in the years 1887, 1889, 1891 at the Paris Observatory.

At that time there was planned in minutest details the great undertaking of the "Chart of the Heavens." Upon this work, at the present moment, eighteen observatories are busily engaged, all working upon the same plan, the same scale, with similar instruments.

In a most useful and interesting memoir, Mr. Trépied, Director of the Algiers Observatory, has classified and commentated on the various resolutions adopted by the three successive congresses above mentioned.

For purposes of reference I present the "Index" of Mr. Trépied's memoir (translated from the original text).

1. Photographic Plates.
2. Distribution of the Centers of Plates.
3. Selection of Guiding-Stars.

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* Presented at the Congress of ASTRONOMY AND ASTRO-PHYSICS, Chicago, August, 1893.

4. Use of the "*Réseau*" (horizontal lines crossing vertical lines traced on a silver plate).
5. Focusing of Photographic Instruments.
6. Orientation of Plates.
7. Limits of Star Magnitudes for the Two Series of Plates (Catalogue and Chart).
8. *Modus operandi* of the Plates of the Catalogue.
   Modus operandi of the Plates of the Chart.
9. Developing of Plates.
10. Preservation of Plates.
11. Inscriptions on Plates.
12. Measurements and Instruments of Measurement.
13. Reproduction of Plates.
14. Distribution of the Work between Coöperating Observatories.

PHASES OF THE BUREAU.

In September, 1891, the regular work of the Chart of the Heavens and of the Catalogue was begun at the Paris Observatory. One hundred and thirty-three plates were taken up to January 1892. The following year (1892), the work was somewhat delayed on account of the construction of the new laboratory and the new pavilion for the "Bureau of Measurements," notwithstanding MM. Henry have been able to take 82 photographs of the Chart (exposure 40 minutes) and 173 photographs for the Catalogue.

1889.—Formation of one or more bureaus.

The moment had come to utilize the stellar photographs.

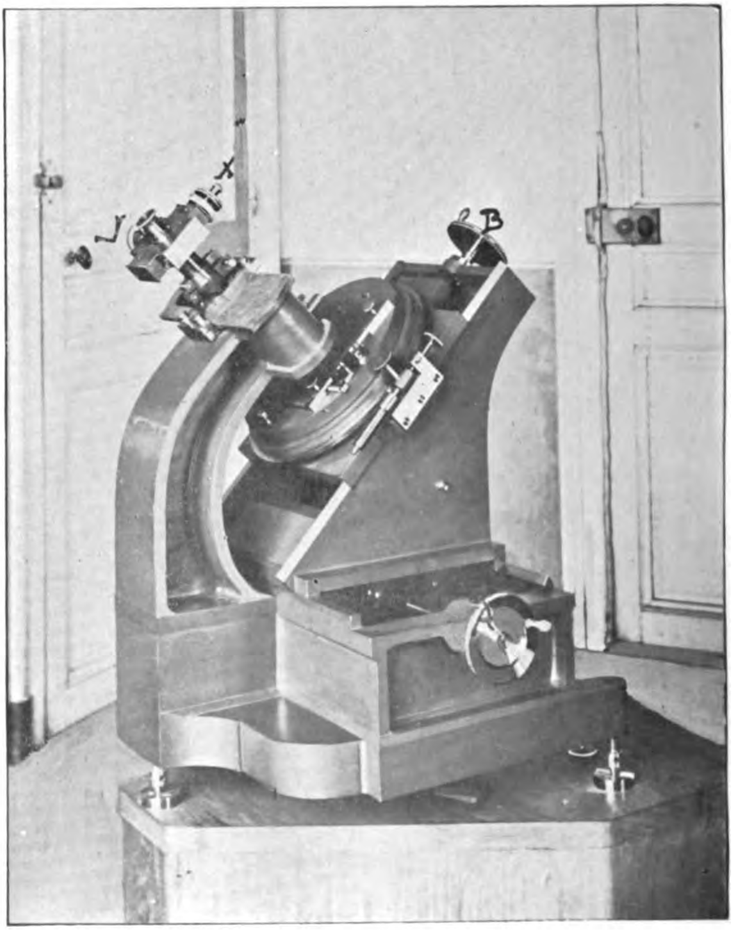
The Congress of 1889 had appointed a committee of seven members to study the question in all its bearings, to devise a plan for the proper construction of instruments of measurement. Also at this time, the Congress recognized the desirability of creating one great bureau embracing within itself all necessary requirements, or several minor bureaus in case the observers should find themselves unable to measure their own photographs.

1891.—In 1891, the committee formulated the following resolution (No. 12, translated from the French):

"As soon as may be judged convenient, each observer will make or have made by whatsoever Observatory or Bureau of Measurements he may choose:"

1st. "The measures, in rectilinear coördinates of the positions of the stars of the Catalogue (each star being measured with reference to the nearest lines of the *Réseau*).

PLATE XL.



Apparatus for Measuring Photographic Plates at the Paris Observatory.

2nd. "The necessary measurements for the determination of stellar magnitudes."

Resolution No. 12 established that, in general, the stars of the plates of the Catalogue should be measured in reference to the lines of the *Réseau*; however, it excludes no special method of measurement, (*viz.* see *Monthly Notices*, 1893, measuring apparatus at Greenwich Observatory.)

For the parts of the heavens extremely rich in stars, Dr. Gill and Professor Kapteyn have contrived a parallactic instrument by means of which measures can be made rapidly and with sufficient accuracy. (See *Bulletin de le Carte du Ciel.*) Through the generosity of M. Bischoffsheim, the Paris Observatory has been endowed with a parallactic instrument which has recently been constructed by M. P. Gautier.

A simple and more convenient apparatus, has been devised for the Bureau of Measurements at the Paris Observatory.

BUREAU OF MEASUREMENTS.

The Bureau of Measurements was organized at the Paris Observatory early in February 1862. Its present staff: Dorothea Khempke, Directress; Assistants: Wm. Schott, Mlles. Thomy, Duguen, Marquett, Coniel.

Herewith are sent two views of said Bureau one view of instruments.*

Measuring Instruments—Description. The measuring instrument is similar in many respects to the macro-micrometer of MM. Henry, which was constructed by M. Gautier in 1884. With this instrument the Paris Observatory made its first measures of photographed binary stars. (See *Rapport Annuel*, 1885.)

The instrument of the Bureau of Measurements has been described by me in the *Rapport Annuel sur l'état de l'Observatoire de Paris pour l'année 1892.* Translation can be found in the *American Journal*, ASTRONOMY AND ASTRO-PHYSICS, of June, 1893.

Description. The instrument is composed of three principal parts.

1st. A fixed horizontal piece.

2d. An inclined plane upon which is placed the plate under examination.

3d. A curved piece supporting the little telescope. Each plate when once in position is susceptible of three motions.

1st. A rotary motion, turning to set plate in invariable direction.

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* A photograph of one of the instruments only accompanied this article. See August ASTRONOMY AND ASTRO-PHYSICS, page 590.

2d. A rectilinear motion of plates on the inclined plane.

3d. A rectilinear motion of the inclined plane on the horizontal plane.

* * * * * * * * * * * * *

Each instrument (at present the bureau possess two) is handled by two assistants taking turns; one making settings, the other recording measures. The stars of the plate under examination are measured by the two observers. Each makes one setting on the two images of the stars, and one setting on each of the four lines of the *Réseau* comprising it.

In the measnrements of the plates the lines of the *Réseau* play most important part.

The Congress of 1887 decided that each photographic plate should bear the impression of a system of lines derived from a *Réseau*, by means of which lines all errors produced by distortion of the film should be eliminated.

The lines of the *Réseau* are 130 mm. long, distant from each other by 5 mm. Thus each plate presents 67.6 squares, easily read on the plate as well as on the apparatus when in place.

By means of two screws, A, B, each 18 cm. in length with pitch of 5 mm., the 67.6 squares of the plates are successively brought into the field of the little telescope. Further, by means of two micrometric screws, X, Y, also of two double spider threads, the distance of the stars in any one square is measured in reference to the lines. The centre of each plate and the value of one revolution of the screw are ultimately determined by the positions of fundamental stars photographed on the plate.

In order to eliminate false stars which may appear on the plates after the *Réseau* is once impressed upon them, the conference of 1892 thought it wise to recommend two exposures on the same plate, one of 5^m the other of 2^m 30^s, the distance between the two images of any one star being from $\frac{2}{10}$ to $\frac{3}{10}$ of a millimeter. Thus each plate of catalogue bears two impressions of each star individually measured by placing the double spider-threads at an equal distance from the center of the disc.

In the plates recently executed, one finds a third photographic image of stars which corresponds to an exposure of 20^s made upon the proposal of Mr. Christie. These short impressions are measured in case of bright stars. They are useful in determining stellar magnitudes, in testing the transparency of the atmosphere.

The measures of one star are composed of sixteen settings.

The photographic images are well defined generally, each disc being of equal intensity within a circle of two degrees. In the corners of the plate they are elongated, presenting the shape of an ellipse.

SOME MEASUREMENTS MADE IN THE BUREAU OF MEASUREMENTS.

The stars, in number one thousand, found on the plate Nos. 187, 185, 201, 202, 203, were measured and reduced in the Bureau of Measurements during the year 1892.

Their final results were used and discussed by M. Loewy in order to test his new method of *raccordement* (overlapping).

M. Loewy comes to the following conclusion:

"The discussion of the plates 187, 185, 203, 202, 201, shows that the total error affecting the relative positions of a star does not exceed ± $0''.11$. In this very small number are comprised all the atmospheric and optical influences and effects that may modify the apparent position of two neighboring stars, the distortion of the plates and of the film, the imperfections of the *Réseau*, all instrumental errors, accidental errors of measurements and personal equation in settings."

THE WORK OF THE BUREAU OF MEASUREMENTS.

During the first year of the Bureau there have been measured 2,600 stars, viz., 1,440 from the 23d of February to October 29; 1,160 from October 31 to December 30. Early in November the method of observation was considerably simplified, the number of settings on each star being reduced from eighty to sixteen.

The second apparatus was delivered on the 20th of March.

The stars measured during the current year with both instruments are 9,618 in number. 5,384 having been measured with the first apparatus and 4,334 with the second.

Thus from Feb. 23, 1892, to July 26, 1893, the Paris Bureau of Measurements of the Paris Observatory has determined the positions of 12,218 stars.

With this number compare those of the following catalogues:

Flamsteed	3310	Piazzi	7646
La Caille	9776	Rümker	11978
Bradley-Bessel	3222	Baily	8377*

Should the Bureau of Measurements continue its work under the present conditions, it would be able to measure in two years $\frac{4}{10}$ the number of stars contained in Lalande's Catalogue, in five years $\frac{2}{10}$ those of Weisse's Catalogue; in three years $\frac{7}{10}$ those of Cooper's Catalogue, in six years Shoenfeld's Catalogue, in sixteen years $\frac{8}{10}$ Argelander'sCatalogue.

The beloved, the excellent Admiral Mouchez in his *Photographic Astronomique a l'Observatoire de Paris et la Carte du Ciel* was right in declaring that, "It will soon be no longer necessary to use great and costly instruments to tire one's health spending nights in maneuvering them, in waiting for favorable circumstances; neither will it be necessary to travel to other hemispheres in order to study certain regions of the heavens, invisible in our own latitudes; all these operations will be transformed in a study done at leisure at the microscope; a study commodious, easy, inexpensive, within the reach of all workers curious of things in Nature. To all of these it is given to penetrate more profoundly into the heavens than can be done to-day (1885) by the majority of professional astronomers."

PARIS, July 25, 1893.

ON THE PERIOD OF THE FIFTH SATELLITE OF JUPITER.[*]

E. E. BARNARD.

No satisfactory observations of the fifth satellite of Jupiter have been obtained this apparition of the planet until September 15th when it was seen and measured before its eastern elongation. Twenty-one distance measures were made and from these the time of elongation was computed by the formula

$$T = t \pm \frac{1}{0^\circ.502} \cos - 1 \frac{\delta}{\Delta}$$

where δ = the measured distance of the satellite, Δ the apparent elongation distance, and t the observed time. The motion of the satellite in one minute being 0°.502.

From these measures the following independent times of elongation (T) were obtained. They are in standard Pacific time (8 hours slow of Greenwich).

$17^h\ 40^m.0$	$17^h\ 38^m.1$	$17^h\ 36^m.4$
17 37 .8	17 35 .0	17 35 .0
17 36 .4	17 36 .5	17 36 .0
17 38 .4	17 35 .3	17 39 .7
17 37 .5	17 33 .6	17 37 .2
17 39 .2	17 38 .0	
17 35 .8	17 34 .8	Mean = $17^h\ 36^m.9$
17 40 .2	17 34 .8	

Combining with this an observation (from measures) of an eastern elongation 1892 Sept. 10 ($12^h\ 47^m.5$), the following period is derived

$$P = 11^h.57^m\ 22^s.56$$

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[*] Communicated by the author.

From my observations last year I had obtained, $P = 11^h\ 57^m\ 23^s.06$ (A. J. 286).

From the same observations Mr. A. Marth had also derived a period, $P = 11^h\ 57^m\ 21^s.88$ (M.N. Vol. LIII, pp. 490-492). It will be seen that the present determination, covering a period of 743 revolutions of the satellite, falls nearly mid-way between Marth's and my previous determination.

It is $0^s.50$ less than mine and $0^s.68$ greater than Marth's.

In the above determination the observations have been corrected for parallax and aberration.

The satellite seems to be about eight minutes behind Marth's ephemeris in the *Monthly Notices* referred to.

The delay in getting observations of this object this year was on account of the elongations falling one too early and the other too late in the night (*i. e.* morning).

At the present observations, though the satellite was faint, it was fairly well seen.

MT. HAMILTON, 1893, Sept. 17.

METEORIC ASTRONOMY II.*

DANIEL KIRKWOOD.

TUTTLE'S COMET AND THE PERSEIDS, OR AUGUST METEORS.

The frequency of shooting stars in August was observed as long since as the middle of the eighteenth century. The fact that a maximum occurs, almost invariably, about the 9th or 10th of the month was announced by Quetelet, of Brussels, in 1835. In clear nights at that time the meteors may always be observed. The numbers are much less considerable than those of November 13th; varying in different years from 20 to 200 per hour. They may be observed in the early part of the night. The November meteors, on the contrary, are rarely seen before midnight. The tracks of the former, when produced backward, intersect in Perseus; hence their designation, *Perseids*.

Meteors observed during August in the ninth, tenth, and more recent centuries, are now known to have been derived from this Perseid cluster. The following catalogue includes all known to the present writer down to A. D. 1819. In later years, only the more important have been selected.

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* Communicated by the author.

PERSEID METEORS.

A. D.	811	Cluster A.	A. D.	924	Cluster B.
	820			925	
	824			926	
	830			933	
	833				
	835				
	841				

A. D.	1243			A. D.	1800	August	10th
	1451				1801	"	8th
	1709	August	8th		1806	"	10th-11th
	1779	"	9th-10th		1809	"	10th
	1781	"	8th		1819	"	6th*
	1784	"	6th-9th		1831	"	10th
	1798	"	9th		1853	"	10th
	1799	"	9th-10th				

The fact that the August meteors move in the orbit of the third comet of 1862 was discovered by Schiaparelli. A comparison of the dates at which they have been observed seemed to indicate 105 years as the meteoric period. The conclusion, however, was very uncertain. The period of the comet, according to Oppolzer, is 121.502 years.† It seems impossible to trace clearly a series of consecutive returns in the preceding list of meteor showers. A close inspection, however, points with considerable probability to the same or nearly the same period—about 122 years. Thus:

A. D. 811 to	A. D. 933	1	period	of 122		years.
820 to	1798	8	"	of 122		"
824 to	1801	8	"	of 122		"
830 to	1806	8	"	of 122		"
833 to	1809	8	"	of 122		"
835 to	1811	8	"	of 122		"
841 to	1451	5	"	of 122		"
924 to	1779	7	"	of 122		"
933 to	1789	7	"	of 122		"
1243 to	1853	5	"	of 122		"
1451 to	1819	3	"	of 122	+	"
1709 to	1831	1	"	of 122		"

The facts point to an indefinite antiquity of the cometic and meteoric clusters; to a *slow* change in the relative positions of the principal parts; and to a more considerable disturbance of limited sections.

Tempel's comet of 1866 and Tuttle's meteor comet of 1862 have both retrograde motion. Other well known bodies of this class, as we shall find hereafter, are direct. Their phenomena,

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* "During the night of August 6, an aerolite was seen at sea passing from N. E. to S. W. It was preceded and followed by the appearance of a great number of shooting stars."—Quetelet.

† *Annuaire*, 1884, p. 193.

their physical history, the cause and circumstances of their disintegration, etc., etc., will be fruitful themes for the astronomer of the future.

TUTTLE'S COMET—1862 III. THE SOURCE OF THE PERSEID METEORS.

The third comet of 1862 was discovered by Tuttle, at Cambridge, U. S., four days before its perihelion passage. On the 24th it became visible to the naked eye, having then a diameter of 8′, and a tail 1° 30′ in length. On the 27th of August the train was from 27° to 30° in length and the apparent diameter 17′. The comet in 1862 was easily visible to the naked eye, and as its associated meteors have been occasionally seen, widely dispersed, for more than ten centuries, it is highly probable that the comet itself has been a member of the solar system for several thousand years. That the visit of 1862 was the only one at which it was seen seems wholly improbable. Its brilliancy, of course, has depended upon its position with respect to the Earth, but it could hardly have escaped detection at *every* return. What is the testimony of ancient records?

With a period of 121.5 years former returns would have been due about the years named below. Those in which comets appeared are marked by an asterisk. The dates are carried back to the meteoric epoch early in the ninth century.

Returns in A. D.	1862*	Observed.	1255 or 1254*	Calculated.
	1741	Calculated.	1133*	"
	1619*	"	1012*	"
	1498	"	890*	"
	1376*	"		

NOTES.

1. A large fire ball moving in a shower of Perseids, is the phenomenon recorded in Quetetet's catalogue for August, 1819.

2. Recorded facts sustain the following history of the great comet of 1862, and of the thence derived shower of Perseid meteors:

It is generally admitted by astronomers that comets enter the solar system *ab extra*, move in conic sections about the Sun, and if undisturbed by the planets, again pass off from the system to be seen no more. If in their motion, however, they approach very near any of the larger planets, their direction is changed by perturbation—their orbits under certain circumstances, being transformed into ellipses. Such, according to the accepted theory, was the origin of the meteor-comet of 1862. The epoch of its entrance into the solar system is unknown. The cause and nature of the catastrophe by which a change was effected in its physical constitution are also unknown. At a distant epoch, however, the bonds which united it as a single body were disrupted. The gaseous portion, or that lightly held by the force of gravitation, escaped from the control of the hitherto governing mass, in the form of meteors. The process of disintegration has continued through successive centuries. The orbit intersects that of the Earth in the point passed by the latter about the 10th of August. This cometic matter passing through the atmosphere with great velocity becomes ignited and presents the appearance of luminous meteors. The future of such phenomena cannot be foretold.

3. It is not impossible, or even improbable, that meteor clusters may have been drawn by planetary influence from the track intersecting that of the Earth, so that for a particular section the phenomena of shooting stars may be no longer seen. On the other hand new orbits and periods may result from similar disturbances.

THE ORBIT OF β 416.*

S. W. BURNHAM.

Herschel at the Cape of Good Hope noted a distant companion to the star Scorpii 185, about 30″ from the primary, and entered it as No. 4935 of his catalogue. In 1876, when looking it up with the 6-inch, I found that the large star had a much nearer attendant, the distance being estimated at that time as 1″.8. It was measured in the following year at Cincinnati and Sydney. When it was next examined by me in 1888 at Mt. Hamilton, it was apparent that rapid motion had taken place in the angle. I measured the close pair every year but one during my stayon Mt. Hamilton, and as the distance steadily diminished, the angular movement was correspondingly more rapid from year to year.

After the measures of 1892 were made, I obtained the orbit by the graphical method from all the measures, the angular motion then being about 200°. Since that time two other orbits have been computed, one by Gore (*Monthly Notices*, March, 1893) and the other by Glasenapp (ASTRONOMY AND ASTRO-PHYSICS, May 1893.) These are marked respectively A and B on the accompanying diagram.

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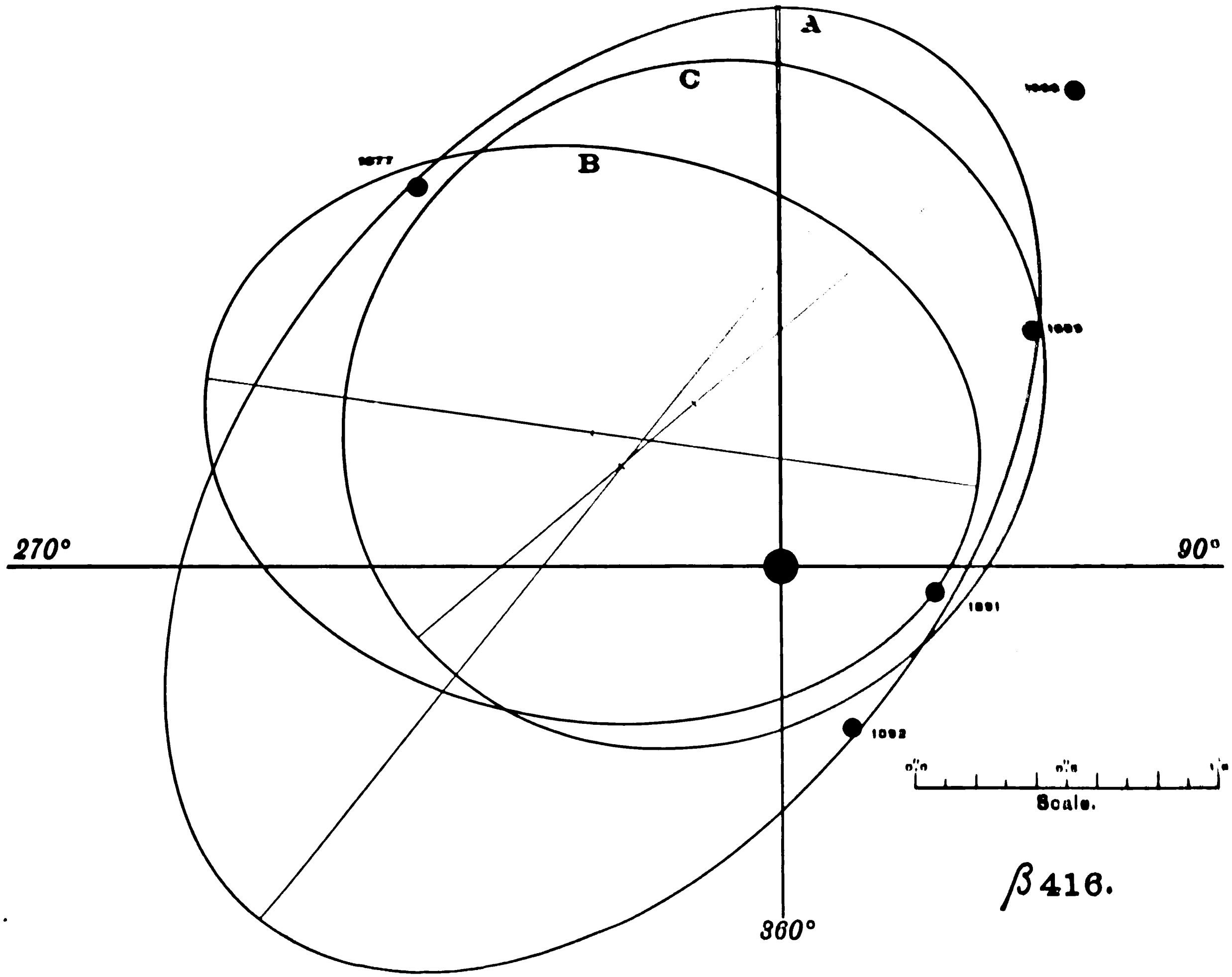
* Communicated by the author.

PLATE XLI



β416.

As these several investigations give very different results in the elements of the orbits, and in the apparent ellipses which represent the path of the companion, and as all have used precisely the same data, it will be interesting at this time to examine them as laid down on the same sheet. It will be seen that the measures have been differently treated in the adjustment of the angles and distances. To some extent this may be explained by the methods employed.

The following are the elements of the respective orbits:

	Gore.	Glasenapp.	Burnham.
	A	*B*	*C*
P =	3448 years	34.85 years	24.7 years
T =	1891.85	1892.00	1892.26
e =	0.556	0.65	0.56
a =	2″.13	1″.52	1″.46
i =	56°.7	45°.4	44°.4
Ω =	139°.4	104°.3	122 .0
λ =	278°.2	300°.7	93 .5

At this time is is impossible to say which of these ellipses will best represent the orbit, but it is certain that the measures of this year and the next year will substantially determine the question. I examined this star during the present season with the 18½-inch of the Dearborn Observatory, but in this latitude the star is so near the horizon I could do no more than see that it was apparently double. So far as one could judge, the distance had not sensibly increased since my measures in 1892.

The position of this pair (1880) is:

R. A. 17^h 10^m 47^s
Decl.—34° 51′

I have previously called attention (*Sidereal Messenger*, December, 1891) to the very rapid motion of this system, considering the distance of the components, and suggested that it may be comparatively near our system. It would be well for some observer in the southern hemisphere to investigate the parallax of this star. The Herschel companion is admirably well placed for this purpose.

CHICAGO, Sept. 1, 1893.

THE ORBITS OF COMET 1889 V.*

H. C. WILSON.

This comet was discovered by Mr. W. R. Brooks, then of Phelps, N. Y., July 6, 1889. It was a rather faint telescopic object and would not have attracted very much attention, but for the fact

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* Communicated by the author.

that it was moving in a short ellipse with a period of about 7 years, and that in the year 1886 it must have passed very close to the planet Jupiter and its orbit must then have been very greatly changed. This was pointed out by Mr. S. C. Chandler, in No. 204 of the *Astronomical Journal.* In a later paper (*Astr. Jour.* No. 205), Mr. Chandler gave the results of a rough calculation of the principal perturbations by Jupiter, that is from Jan. 24 to Sept. 14, 1886, and attempted to trace the course of the comet backward from that time. He found that the encounter with Jupiter in 1886 effected a complete transformation of the comet's orbit. Instead of the present small seven-year ellipse, it was previously moving in a large one of about 27 years period, whose aphelion lay outside of Saturn's orbit, and whose perihelion was almost exactly at the present aphelion distance. The direction of the lines of apsides and nodes were reversed and turned through an angle of about twenty degrees. The plane of the orbit was also tilted about fourteen degrees.

Furthermore, tracing back the course of the comet with the elements of the twenty-seven year ellipse Mr. Chandler found that the comet must have been very near Jupiter in the year 1779, the very time when the lost comet of Lexell 1770 was in the immediate vicinity of the planet and suffered the notable disturbance which was supposed to have taken it out of our reach. This coincidence of time and place afforded a strong presumption of the identity of the two comets. Later computations do not confirm this presumption but there remains the very interesting and difficult problem of determining exactly the course of a comet when under the preponderating influence of a great planet.

In recent numbers (302 and 303) of the *Astronomical Journal*, Mr. C. L. Poor has given the results of his investigations in regard to Comet 1889 V. He used as the basis of his work the definitive elements of the comet's orbit computed by Dr. Julius Bauschinger from all the published observations, the latter extending over a period of over eight months. There is still some uncertainty expressed by the factor ν, in these elements, not due to the computations but to the inaccuracies of the observations. Mr. Poor finds that ν is probably within the limits — 40 and + 40. This uncertainty is very slight but enough to affect, to some extent, the character of the calculated approach of the comet to Jupiter. Taking the most probable values of the elements and calculating the perturbations by all of the planets, which could preceptibly influence the comet's motion, back to 1886, Mr. Poor finds that the approach was closer than Mr. Chandler had supposed. The nucleus of the comet passed within the orbit of the first satellite and may have almost grazed the surface of the planet itself.

In calculating the path of the comet when very near to Jupiter Mr. Poor followed the method of transforming the elements of the elliptic around the Sun into those of a hyperbola around Jupiter, regarding the Sun as a disturbing body. This transformation was made at the date Oct. 26.5, 1886. After tracing the movement of the comet back around Jupiter for six months the elements were again referred to the Sun as a center at the date March, 24.5, 1886, and it was found that the orbit had so greatly changed that the period was then 41.87 years. For several months before that time, however, the perturbations by Jupiter had been large and when these were calculated back to March 14.5, 1884, the elements were found to give a period of 31.38 years, with the perihelion passage July 20, 1886. Mr. Poor thinks that the uncertainty of this period is within two years.

It is interesting to place side by side the elements of the comet's orbit at the various stages of its transformation. We can give here only the elements obtained on the supposition that $\nu = 0$. Mr. Poor gives seven sets of elements corresponding to different values of the factor of uncertainty ν.

ELLIPTIC ORBIT ABOUT SUN.

	1869 Sept. 30.5 Berlin M. T.		1886 Oct. 26.5 Gr. M. T.	
M =	0° 01′ 05″.01 + 1″.0ν		213° 15′ 46″.82	
π =	1 34 54 .99 − 3 .0767ν	1890.0	2 35 23 .59	1886.0
Ω =	17 59 04 .37 − 0 .0174ν		19 02 59 .88	
ω =	343 35 50 .62 − 3 .0593ν		343 32 23 .71	
i =	6 04 06 .57 − 0 .1140ν		7 27 03 .80	
φ =	28 05 05 .75 − 1 .3961ν		31 48 33 .33	
μ =	501″.72306 + 0″.0114ν		522″.09375	
a =	3.684350		3.587900	

HYPERBOLIC ORBIT ABOUT JUPITER.

	1886, Oct. 26.5 Gr. M. T.	1886, March 24.5
π =	283° 41′ 55″.12 + 249″.59ν	284° 13′ 39″
Ω =	258 10 11 .80 − 14 .21ν	256 08 56
i =	74 52 08 .00 − 120 .66ν	63 42 15
F =	76 34 22 .82 + 19 .30ν	−77 38 50
a =	−0.0856771 + 0.000010274ν	−0.0884240
e =	1.0097088 + 0.000179192ν	1.011393

ELLIPTIC ORBIT ABOUT SUN.

	1886, March 24.5		1884, March 14.5	
L =			161° 49′ 54″	
π	187° 14′ 00″.7	1886.0	188 46 12	1886.0
Ω	183 17 16 .8		186 19 14	
i	7 39 17 .6		6 45 44	
ω	3 56 43 .9		2 26 58	
φ	33 12 05 .4		26 47 33	
μ	84″.7435		113″.0620	
a	12 .05776		9 .94298	
T	1886, June 24.0752		1886, July 20.2416	

For the benefit of those who do not readily interpret the elements we have attempted to represent them graphically by means of the diagrams, Figures 1 and 2. In Fig. 1, the four elliptic orbits are shown together with the orbits of Earth, Jupiter, Saturn and Uranus. The four ellipses of the comet's path all meet near that point of Jupiter's orbit which is opposite the vernal equinox. For two of them this is the most distant part of the orbit (aphelion) for the other two it is the nearest part (perihelion). One can see at a glance what a tremendous change in the path of the comet occured between March and October, 1886.

Interpreting the elements with the aid of the figure they tell us that the comet previous to 1884 was moving in a large ellipse, the nearest point of which to the Sun lay very close to Jupiter's path, and the farthest point about half way between the orbits of Saturn and Uranus. The plane of the orbit was inclined at an angle of about 7° to ecliptic and the orbit crossed the latter from south to north in longitude 186°, very near the path of Jupiter. This orbit is represented in Fig. 1 by the line marked "Orbit of Comet 1889 V in March, 1884." The comet was describing this path at the rate of a revolution in about 31.38 years. Had it not been influenced by Jupiter it would have gone around this orbit again and again and never have been seen from the Earth. As it happened to come to perihelion at the same time that Jupiter was in that vicinity, its was drawn, at first very gradually, then more rapidly, from the large smooth curve of figure 1 into the larger dotted curve, then into the smaller dotted curve, and finally and gradually into the slightly larger smooth curve. This last curve, "Orbit of Comet 1889 V in 1889," it will continue to follow for several revolutions of seven years period with only slight modifications by the planets. In 1921 another close approach to Jupiter will occur, which, though not so close as the one in 1886, will considerably change the orbit, probably making it larger and possibly removing the comet from the reach of our telescopes for a long period.

Fig. 2 represents a portion of the hyperbolic orbit of the comet relative to Jupiter while it was passing through the system of the satellites, and is especially interesting in showing how very close the comet came to the planet and the satellites. The scale is nearly 4000 times that of Fig. 1 The time of nearest approach to Jupiter was found to be July 20 when the distance was only 2.31 radii of the planet, with the uncertainty expressed by r in the formula

$$q = 2.31 + 0.033r$$

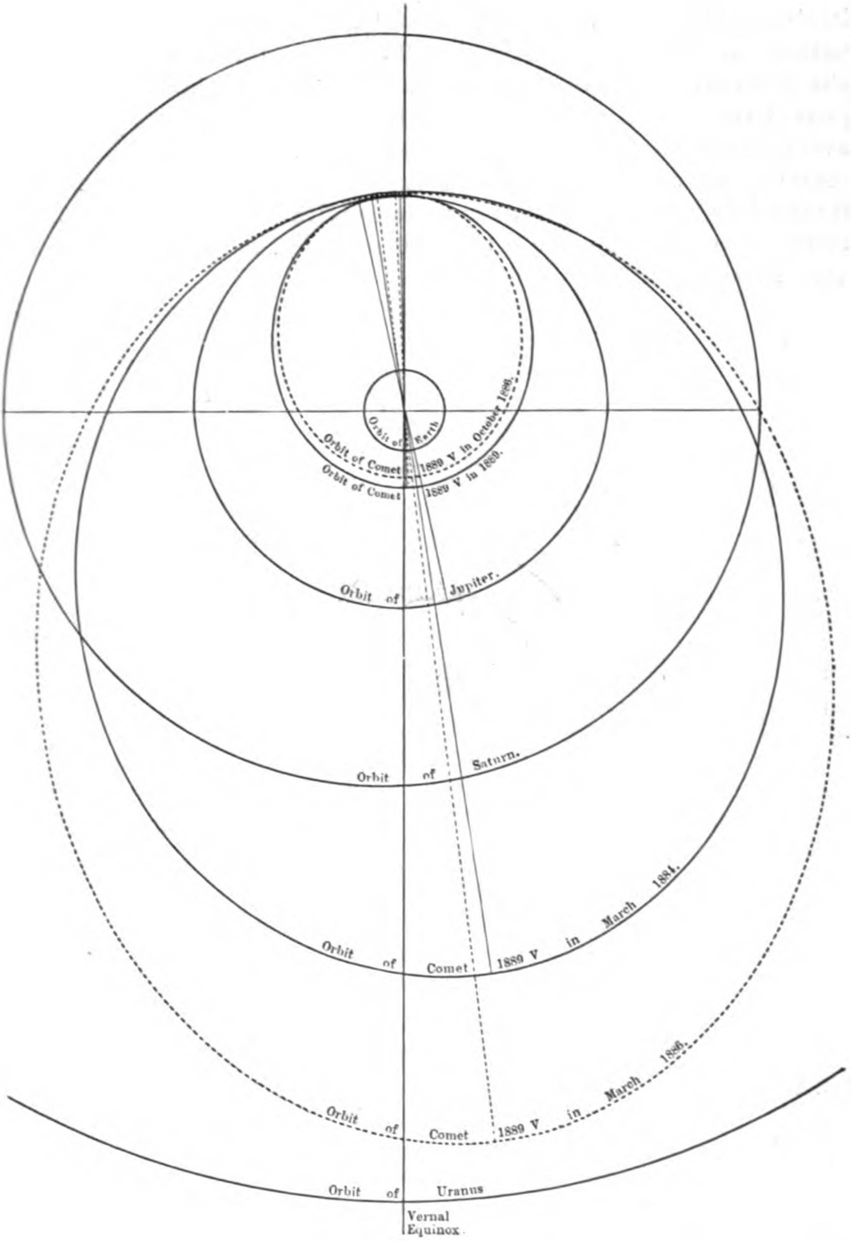
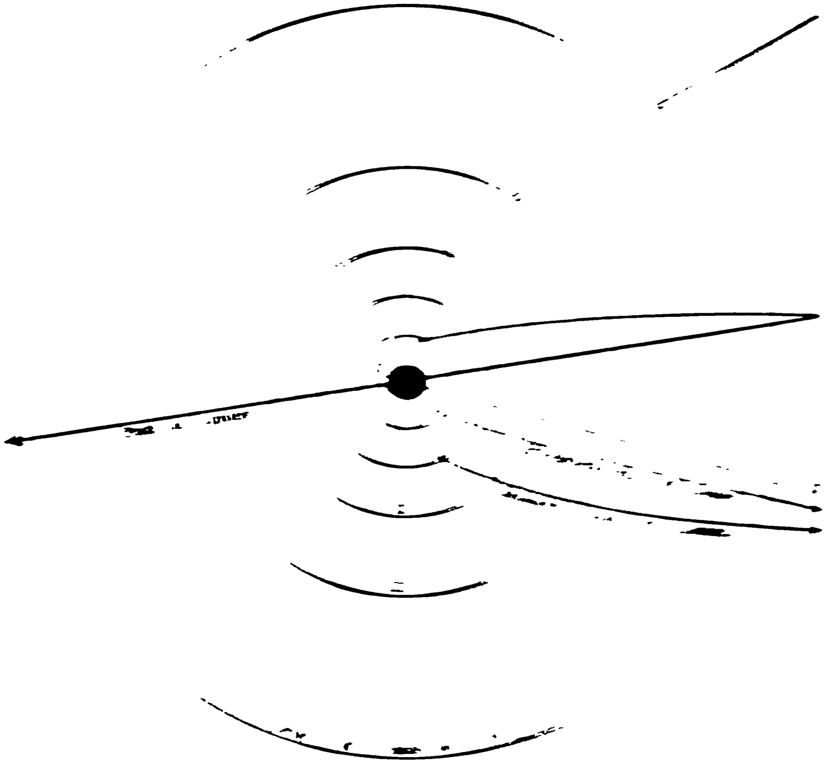


FIG. 1.—THE ORBITS OF COMET 1889 V BEFORE AND AFTER ITS APPROACH TO JUPITER IN 1886.

That is, the comet not only passed through the system of Jupiter's satellites, but it actually passed within the orbit of the first satellite whose mean distance is [illegible] radii of the planet. Taking the extreme limits of [illegible] we are safe in saying that the comet passed the centre of Jupiter at a distance not greater than 3.63 and not less than [illegible] radii of the planet. In other words the centre of the comet may have grazed the surface of Jupiter, and it certainly approached that surface to within a distance of 2.63 radii of the planet, or only [illegible] miles. Even this latter is a very small quantity.



[illegible]

[illegible] distance [illegible]

the system in longitude 71°. During this time it must have collided with one or more of the satellites."

The last two paragraphs are quoted from Mr. Poor's paper. In Fig. 2 the circles represent the orbits of Jupiter's satellites and the relative path of the comet is almost a parabola and was drawn from the mean of the hyperbolic elements given for Oct. 26.5 and March 24.5, 1886. It is necessary to understand that the path of the comet is in a plane inclined at an angle of about 70° to the plane of the satellite orbits, so that the comet did not pass horizontally across them, but came up through from below. The line NN′ represents the line of nodes or intersection of the planes of the comet's path and the ecliptic.

The reader must understand, too, that this is only the path relative to Jupiter and that the latter was at the same time moving rapidly along its orbit, so that while the comet, after July 20, was apparently moving backward with reference to Jupiter, with reference to the Sun it was moving forward and changing from the larger dotted orbit to the smaller one in Fig. 1.

It will be noticed that the path of the comet passes very close to that of the new satellite (V) of Jupiter and suggestions have already reached us from different sources, that possibly this comet had something to do with the origin of the new satellite, that in fact the satellite is a captured fragment of the comet. We cannot see how this could be, with the comet passing through the system just as it did, and, supposing the capture to have occurred, cannot account for its brilliancy, since the whole comet was invisible long before it reached the distance of Jupiter.

If the period of 31.38 years is correct this comet cannot be identical with Lexell's comet of 1770 unless marked perturbations occurred between 1886 and 1779 when the latter was in the vicinity of Jupiter and had its orbit greatly changed, for the interval 107 years is not a multiple of 31.38 years or any number very near that. Mr. Poor finds that there was no very near approach of the comet to Saturn in that interval but that possibly a very close approach to Jupiter occurred in 1791. This however, would be fatal to identity with Lexell's comet, for it would require the comet between 1779 and 1791 to have a period equal to that of Jupiter, that is an identical orbit.

Mr. Poor also tests the question by means of M. Tisserand's formula

$$n = \frac{1}{a} + \frac{2\sqrt{A}}{R^2}\sqrt{p}\cos i$$

and finds that for the four sets of elliptic elements of Comet 1889 V, at the epochs March, 1884, March, 1886, Oct., 1886, and Sept., 1889, the values of *n* agree, while that from the elements of Lexell's comet is decidedly different. The question of the disruption of the comet and the possibility that a portion of it was drawn permanently into Jupiter's system he proposes to discuss in another paper.

THE JUPITER FAMILY OF COMETS.*

W. W. PAYNE

Some little time ago we had occasion to look up the comets supposed to belong to the family of Jupiter in connection with the study of the Holmes' comet, a recent member of the notable group. Thinking that an illustration of the several paths of these comets in connection with the orbit of Jupiter would be interesting to the readers of *Popular Astronomy*, they were projected carefully, and very nicely engraved as the accompanying plate shows. Not knowing of any illustration that is nearly so complete as this, we ventured to give it place for convenience in reference. We do not feel sure that all the comets found in the following table rightly belong to this family, neither are we very certain that there are not others which might as well be reckoned in the list as some which find place there. At all events the diagram and the table of elements are arranged and put in this form after much pains in search for best and most reliable results.

Another point of interest is that which is spoken of by most late writers who refer to such cometary groups with much particularity, and that is the tendency of the perihelion points of the orbits to cluster in one region lying in the general direction of the vernal equinox. This seems to be manifestly the case in the Jupiter family. Why this is so, we are not aware that authors offer any very satisfactory reason. The only one that has occurred to us depends on the "capture theory," which is itself not generally accepted by astronomers as proved, but which has, at least, a good degree of probability. The "Sun's way," so-called, is nearly in the direction indicated by the bottom of the chart. Jupiter's absolute motion in the region of the autumnal equinox must equal his mean motion plus that of the "Sun's way," approximately. Jupiter therefore would overtake or meet more comets in that part of his orbit than in others, and so the possibility of disturbing influence in that region would be greater than elsewhere. This may not be new, but we have not seen the statement before. The chart is taken from *Popular Astronomy*.

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* Communicated by the author.

ELEMENTS OF THE JUPITER FAMILY OF PERIODIC COMETS.

Comets of which more than one apparition has been observed.

Name.	Period in yrs.	Time of Perihelion Passage.	Perihel'n Distance	Aphelion Distance	*e*	π	☊	*i*	Mean Equinox	Calculator and Reference.
						° ′ ″	° ′ ″	° ′ ″		
Encke	3.303	1891 Oct. 17.986	0.34047	4.09489	0.84647	158 38 46	334 41 27	12 54 58	1891.0	Backlund, Astr. Gesel. J. 27-1
Tempel	5.211	1889 Feb. 2.101	1.38660	4.66545	0.55210	306 08 03	121 09 17	12 45 05	1890.0	Schulhof.
Brorsen	5.456	1890 Feb. 4.104	0.58776	5.61038	0.81034	116 23 10	101 27 34	29 23 48	1890.0	E. Lamp, A. N. 2933.
Tempel-Swift	5.534	1891 Nov. 14.083	1.08660	5.17088	0.65270	43 14 16	296 31 15	5 23 14	1891.0	Bossert, Astr. Gesel. J. 27-1.
Winnecke	5.818	1892 June 30.893	0.88642	5.58313	0.72297	276 11 09	104 04 59	14 31 31	1890.0	Haerdtl. A. N. 3062. Astr. Gesel. J. 28, p. 142
Tempel	6.507	1885 Sept 25.734	2.07332	4.89733	0.40513	241 21 50	72 24 09	10 50 27	1880.0	Gautier, A. N. 2656.
Biela {Nucleus 1	6.587	1852 Sept 23.718	0.86016	6.16732	0.75520	109 05 20	245 49 34	12 33 28	1852.0	D'Arrest, A. N. 933
Biela {Nucleus 2	6.629	1852 Sept 22.952	0.86059	6.19687	0.75512	108 58 17	245 58 29	12 33 50		
Finlay	6.627	1893 July 12.176	0.98912	6.06371	0.71951	7 41 34	52 27 43	3 02 02	1893.0	Schulhof, A. N. 3171
D'Arrest	6.691	1890 Sept 17.493	1.32404	5.77776	0.62713	319 14 34	146 16 32	15 42 41	1890.0	Leveau, Astr. Gesel. J. 26-1
Wolf	6.821	1891 Sept 3.473	1.59285	5.60058	0.55714	19 11 38	206 22 29	25 14 33	1891.0	Thraen, A.N. 3050, Berberick, A. J. 253, Astr. Gesel. J. 27-1
Faye	7.566	1881 Jan. 22.671	1.73814	5.97009	0.54902	50 48 47	209 35 25	11 19 40	1880.0	Möller, Berl. Jahrb. 1882

Comets of which only one Apparition has been Observed.

Name.	Period in yrs.	Time of Perihelion Passage.	Perihel'n Distance	Aphelion Distance	*e*	π	☊	*i*	Mean Equinox	Calculator and Reference.
1819 IV, (Blanpain)	4.810	1819 Nov. 20.252	0.89256	4.806	0.68675	67 18 48	77 13 57	9 01 16	1819	Encke.
1766 II, (Helfenzrieder)	5.025	1766 Apr. 26.995	0.39898	5.468	0.86400	251 13 00	74 11 00	8 01 45	1766	Burckhardt.
1884 II, (Barnard)	5.398	1884 Aug. 16.483	1.27969	4.872	0.58395	306 11 20	5 08 38	5 27 33	1884.0	Egbert, A. N. 2657
1844 I, (De Vico)	5.459	1844 Sept 2.484	1.18632	5.015	0.61737	342 30 48	63 49 38	2 54 46	1844	Brünnow.
1886 IV, (Brooks)	5.595	1886 June 6.691	1.32772	4.976	0.57874	230 16 51	53 28 57	12 43 26	1886.0	S. Oppenheim.
1770 I, (Lexell)	5.626	1770 Aug. 13.547	0.67431	5.652	0.78684	356 16 27	131 59 34	1 34 31	1770	Le Verrier.
1783 (Pigott)	5.888	1783 Nov. 19.937	1.45929	5.062	0.55246	50 17 25	55 40 30	45 06 54	1783	C. H. F. Peters.
1892 V, (Barnard)	6.309	1892 Dec. 11.05	1.42911	5.396	0.58123	16 52 36	206 38 45	31 12 28	1892.0	Krueger, Astr. Gesel. J. 28 p. 145
1890 VII, (Spitaler)	6.378	1890 Oct. 26.601	1.81791	5.061	0.47144	58 25 58	45 05 52	12 50 44	1890.0	Spitaler, A. N. 3011
1858 III, (Tuttle)	6.609	1858 May 2.974	1.14922	5.894	0.67368	200 46 27	175 04 09	19 30 02	1858.0	Schulhof.
1892 III, (Holmes)	6.909	1892 June 13.238	2.13940	5.116	0.41024	345 53 12	331 42 12	20 47 23	1892.0	Schulhof, A. N. 3140
1889 V, (Brooks)	7.073	1889 Sept 30.012	1.95023	5.419	0.47070	1 26 17	17 58 45	6 04 10	1890.0	Chandler, A. J. 205 A.N. 2952 Astr. Gesel. J. 26 1
1881 V, (Denning)	8.343	1881 Sept 12.834	0.72384	7.503	0.82403	18 10 05	66 09 02	6 53 26	1881.0	Chandler, A. N. 2406
1889 VI, (Swift)	8.534	1889 Nov. 29.572	1.35367	6.998	0.67585	40 15 02	330 36 02	10 14 54	1890.0	Hind, Astr. Gesel. J. 27-1

Astro-Physics.

ON THE SPECTRA OF THE ELEMENTS.*

H. KAYSER AND C. RUNGE.

Our researches have, as we think, conclusively shown that at least in the spectra of a number of elements the distribution of the lines is subject to certain laws:

1. A considerable number of the lines of each spectrum, in many cases the majority, may be arranged in series that resemble the one in the hydrogen spectrum discovered by Huggins. The wave-lengths of the lines forming a series may be calculated by a formula similar to the formula discovered by Balmer for the series of hydrogen lines. If λ be written for the wave-lengths we find

$$\lambda^{-1} = A - Bn^{-2} - Cn^{-4}$$

where A, B, C are positive constants and for n the series of entire numbers beginning with 3 is to be substituted. This formula we first published at the meeting of the British Association at Bath, 1888 (see Rep. of Brit. Ass., p. 576, 1888). Since then we have been occupied with determining the spectra of the elements, as the new methods and instruments of Rowland were so superior as to make the existing determinations of wave-lengths almost worthless. We began by measuring the spectrum of iron, which has served as a scale, and after that the spectrum of the carbon flutings, before we entered on the investigation of the spectra of theelements.

2. All series except those in the spectrum of hydrogen and of lithium may be said to consist of either doublets or triplets of lines. Among those consisting of doublets two different characters appear, series whose doublets are more and more narrow toward the more refrangible side, and series whose doublets retain the same difference of oscillation-frequencies throughout. The former kind has only been observed in the spectra of the alkalis, where there are in each spectrum two series of the latter and one series of the former character. The different character may also be stated thus. For the first kind A and B have the same values in the two formulas that give the first and the second lines of the doublets, while for the second kind B and C have the same values. In a drawing of the spectrum to the scale

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[*] Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

of oscillation frequencies the figure representing the series of the first lines could therefore, for series of the second character, if shifted to the side, be made to coincide with the series of the second lines. In all series of triplets that have been observed the oscillation frequencies of the three lines forming a triplet give the same differences throughout the whole series, which may also be stated thus: The three formulas representing the first, the second and the third lines have the same value for B and the same for C.

3. The value of B is nearly the same in all formulas.

4. If the elements are grouped according to the natural system of Mendelejeff, their chemical relationship is clearly shown in the distribution of the series, which in each family appear to be arranged after a certain plan. For an element of higher atomic weight, the series shift toward the less refrangible side of the spectrum. Thus the spectra of the alkalis show a common plan. So do copper and silver (in the spectrum of gold we have not been able to discover any series). Magnesium, calcium, and strontium show two series of triplets each, arranged correspondingly (in the spectrum of strontium only one was discovered) and so do zinc, cadmium, and mercury. Again aluminium, indium, and thallium show two series of doublets each, also arranged according to a common plan.

5. In each group of chemically related elements, the doublets or triplets, as the case may be, widen with increasing atomic weight. In the spectra of the alkalis the difference of oscillation frequencies is almost exactly proportional to the square of the atomic weight. In the other groups the deviation from this law is greater.

6. The number of lines that do not enter into the series is small for the elements of low melting point and becomes considerable only for the elements of high melting point.

7. The groups of elements investigated belong to the three first columns of the natural system of Mendelejeff. It appears that as a whole from column to column the series shift to the more refrangible side with increasing atomic weight. For this reason we think it possible that in the further columns the series are situated in the most refrangible part of the spectrum and perhaps can not be photographed on ordinary plates, which, as is well known, lose their sensitiveness at about 1900 A. U.

We think that our results are also of some consequence for astro-physics. It is in many cases difficult to decide, whether a certain element occurs in the Sun or in a star. If, for instance, a stronger line of the element is wanting in the spectrum of the star, while a weaker one is observed, it is not safe to conclude that the observed line mustbe an accidental coincidence. For the spectrum of the element in the star may differ widely from the spectrum of the same element in our laboratories, just as much as the arc spectrum and spark spectrum of an element differ. But the argument would be correct if applied to lines of the same series. For it seems certain that lines of the same series correspond to oscillations of the same sort of molecule, so that a weaker line of the series would not appear without the stronger one.

A good many of our results have been anticipated by Rydberg, who published an abstract of his researches as early as 1890, a short time before the publication of our researches on the spectra of the alkali metals. In his elaborate work, however, he refers to our memoir.

ELECTRO-MAGNETIC THEORY OF THE SUN'S CORONA.*

HERMANN EBERT.

Many attempts have been made to establish a connection between the optical phenomena of the Sun perceived through the telescope or fixed on the sensitive plate, and the electrical disturbances which must take place in the Sun or result from the magnetic influences exerted by it. The necessary physical experiments have, however, as I believe, only been attained in later times by the series of experiments and theoretical investigations on electro-magnetic radiation commenced by Hertz. Indeed, we gain by these experiments and by the electro-magnetic theory of light well established by them, explanations of many phenomena of solar physics, otherwise obscure. As an example of this, I wish in the following to sketch an explanation of the Sun's corona from this point of view.

For this purpose there are two points chiefly to be made intelligible:

(1) The filamentary structure of the corona.

(2) Its connection with the period of activity of the Sun, and its zones of activity, for we notice that the corona is widely developed and of streaming radiance at the time of the Sun-spot maximum, that on the contrary it appears small, unimportant,

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

hazy, and without distinct rays, at the time of the minimum; that its strongest rays principally correspond to the region of the spots, etc.

For the explanation we start from the two following premises, the validity of which has never been brought into question, and which form the basis of nearly all solar theories:

(*a*) The regions, where the corona is seen at total eclipses, are not empty, but are completely filled with matter. It has even been said that the corona is really the atmosphere of the Sun. But this does not seem quite correct, because one cannot distinguish in the Sun between the nucleus and the atmospheric envelope as in a planet; according to the solar theory of Mr. August Schmidt, which seems to have much in its favor, that which we call the Sun's surface is only an optical phenomenon caused by total reflections in the fiery masses of gas. Still the gases perceived in the vicinity of this apparent surface by their spectrum, such as hydrogen, helium the D_3 substance, etc., may expand into the real coronal region, if only in the highest degree of rarity. Further there can be no doubt, that in the neighborhood of the Sun, meteoric dust always exists, sometimes collected into clouds; besides this, comets occasionally pass through these regions. On the whole it may be said that to the furthest boundary filled with coronal rays we must take for granted the existence of matter. But this matter is like all other, capable of dielectric polarization; when electric forces are excited in the vicinity of the Sun, all this matter is subject to dielectric polarization.

(*b*) We assume in the second place, that the Sun is the seat of electrical, and therefore also of magnetic forces, for every change in the electric condition of a system is necessarily connected with the appearance of magnetic forces also, and *vice versa*, as appears most clearly in Maxwell's theory.

The Sun is therefore the seat of *electro-magnetic* disturbances.

Electric forces diverging from the Sun were assumed by Fr. Zöllner as explaining the tails of comets and later on in many other theories; they have also been used already in explanation of the corona, but it was imagined that glowing material particles were rent asunder from the Sun's mass and driven forward by electric repulsive forces. However, with this explanation of the coronal rays, we come into collision with dynamical principles.

It was not then known that rapidly changing dielectric polarizations spread out in streams sufficed for this purpose.

In addition to this very simple assumption never called in question in this comprehensive sense, we bring to our aid the two following experimental facts:

(*A*) Theoretical discussions by J. J. Thompson. and experiments with conducting spheres by Oliver Lodge have shown, that when we produce in any manner, disturbances of electrical equilibrium, these complete themselves in the form of oscillations. Such oscillations are communicated to the surroundings, accordto H. Hertz, and migrate from point to point as a wave of electro magnetic radiation with the velocity of light.

The period of the normal oscillations of the whole Sun is 6½ seconds, corresponding to a wave 120,000 miles long in inter stellar space. Generally these disturbances do not affect the entire Sun, but only a portion, and indeed those parts will experience the strongest electric disturbances which also show violent excitement in the telescope or on the photographic plate by the close connection between the electro-magnetic and the heat and light radiation.

(*B*) Another experimental support was afforded by researches conducted during the last two years by Professor E. Wiedemann and myself.* It was found that all rarefied matter, for example, a gas in an electrodeless vacuum tube, or a vapor of low tension, becomes luminous under the influence of very rapidly alternating electric stresses *at those points where the energy varies most.* If therefore, from a conducting surface, dielectric stresses emanate, but *not* with the same density in all directions, then we perceive a luminosity around the surface, not a homogeneous one, but one of definite structure.

With regard to this we come to the following conclusion: The corona is the visible reaction of the finely divided matter in the vicinity of the Sun, upon the dielectric polarizations proceeding from the different parts of the Sun.

That phenomena like the corona are really produced under these circumstances may be shown by simple experiments. It is only necessary to excite, on a conducting ball mounted in a rarefied atmosphere, such periodically changing electric oscillations of slow damp. Then bright radiating streamers will be seen coming out of the ball. To produce the most suitable oscillations I made use of the following arrangement:

The poles of a large influence machine of twenty couples were joined with two plate condensers, the first plates of which discharged themselves through a spark-gap about 300 times a second. The two other plates were connected by two parallel

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* We were aided in these experiments by the Elizabeth Thompson Fund in Boston, and we embrace this opportunity of thanking the administrators of the fund.

straight wires 4 metres long with a third condenser; on the parallel wires a metallic joint, the so-called "bridge," was pushed to and fro until there was an exact resonance between the two parts of the conducting system.

This is Lecher's arrangement, excellent on account of its symmetry, completeness and the long duration of its oscillations.

With one plate of the third condenser a brass ball 1.5 cm. in diameter was connected by a long wire. The ball was fastened and insulated in the centre of a large air-tight glass cylinder (20 cm. in diameter and 28 long) closed at one end by a thick plane parallel glass plate. The cylinder could be filled with different gases and evacuated. When the ball was charged and discharged, during the play of the sparks in the gap, radiating streams came out of it without any conductor on the external surface of the glass cylinder.*

The streams go out from the points of the ball, on which the causes disturbing the electric conditions of the surroundings are most closely massed together, particularly on irregular curved parts of the surface, caused in our experiments by small variations from a true sphere. The phenomena produced in this manner, which I have photographed in some cases, show the following special qualities, and find their perfect analogies in the Sun's corona:

(α) The ball is surrounded by an aureole of light, through which rays shoot in all directions starting from the surface; from this the aureole derives a special structure.

(β) The aureole is very expanded and the ray-like structure comes out very distinctly with strong electric excitement, *i. e.*, with long spark-gap, accordance with the corona's development at the time of the maximum of the Sun's activity, or over the regions of increased activity, *i. e.*, over the spot zones. It is specially observable that sometimes very bright radial streamers shoot out far over the mean limits of the aureole exactly as they do in greatly developed coronas.

(γ) The aureole is small and insignificant, but above all, hazy and structureless with slighter electric disturbances, *i. e.*, in our case with short spark-gaps; this corresponds with the behavior of the corona at the times and regions of the minimum of the Sun's activity.

(δ) There often shoot out of the ball, especially under higher

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* Such a conductor joined with the earth, or the other plate of the condenser was used in our former experiments, and later by Mr. M. I. Pupin (*Amer. Jour. Sci.* (3), 43, p. 463, 1892).

pressure, very long rays in all directions, rays of 12 cm. in lentgh and more, exceeding therefore the ball's diameter eight times and more; they do not always proceed radially from the surface, they even occasionally seem, on account of the perspective, to leave the ball at the tangent. These streams are formed chiefly when the outside wall of the glass vessel is covered with a conducting metallic sheet connected with the earth. This is analogous to the case where widely spread out masses of cosmic dust are in the Sun's vicinity; this is capable of receiving a great deal of energy, because it has greater capability of dielectric polarization than the free ether. We receive in this case the particularly long streams, for which the coronas of some eclipses are famous.

(ε) If the surface from which the stress proceeds be discontinued in some places; if, for example, one fastens a small piece of tin foil on the metal ball, then a stream goes out from its point, but on both sides of it are formed deep black rifts, which extend down to the surface of the ball. These are the well known rifts of the corona.

(ζ) When another conducting mass is brought near the ball, for instance a metal ball suspended by a silk thread, then the streams go out vertically from the surface of the first ball, and bend themselves towards the second, which they endeavor to meet vertically also. In this way the bent rays of the corona arise converging to one point without the Sun. Great masses of iron meteors in the Sun's vicinity must cause such a bending of the corona's rays.

(η) In atmospheric air the streams have a pale red color; in rarefied hydrogen they show a pale silver color; the spectrum is continuous in this case and the slit must be made pretty wide in order to see anything at all. This fact also seems to me very important for the elucidation of the corona, whose spectrum is well known to be continuous, because it is probably only rarefied hydrogen, which fills up the upper regions at great distances from the Sun's apparent surface.

At lower pressure the aureole divides into different parts; with air a thin bluish layer of light lies next to the ball, then comes a dark dividing space, and then the red rays begin. Of these phenomena, called "cathode phenomena," with the ordinary experimental arrangements we cannot see anything near the Sun. But we must not forget that we do not see at all the real origin of the corona rays. For the Sun's surface is probably only an optical phenomenon, as has already been mentioned. But the "cathode phenomena," never appear in free gas space, but only on the boundary of a luminous gas and a rigid body, conducting or non-conducting, as we have shown in the above mentioned treatises.

I should like to take this opportunity of observing that one also obtains with the same apparatus, phenomena which agree altogether with the appearance of comets; standing apparently in the most intimate connection with the Sun's activity. If one attaches on an insulating support, such as a glass rod, a non-conducting body (wax ball) near the metallic ball, then rays arise bending themselves around the wax ball towards the glass behind it, especially when there is an outer shell connected with the earth. One sees a phenomenon like a comet's tail accompanying the wax ball, turned away from the metallic ball in the centre, from which the electric excitement emanates. It is also probable that in comets non-luminous matter comes out of the head and becomes luminous only by rapidly changing electric polarizations caused by electric disturbances in the Sun, like the rarefied gases in our electrodeless vessels.

From this electro-magnetic point of view also, the connection of the Sun's activity and the Earth's magnetism is plausible. This connection was recently denied altogether by some authorities, for example by Lord Kelvin; but the manifold indications cannot be overlooked which are afforded by careful observations, old as well as new, such as the very valuable daily records of the Sun's surface obtained at Kenwood Observatory by Professor George E. Hale, and compared with the magnetic records of the U. S. Naval Observatory, or with the curves obtained by Father Sidgreaves at the Stonyhurst Observatory.

It must be admitted that no magnetic distribution, however created, when rotating on the face of the Sun, can explain the variation of the elements of terrestrial magnetism. We must therefore seek other explanations, and in this respect the above detailed electro-magnetic theory recommends itself. If the Sun is really the seat of electro-magnetic disturbances, then it must necessarily be the source of electro-magnetic radiation. The Earth is a conductor; viewed as an electric oscillator its own period is $\frac{1}{17}$ of a second. The oscillations proceeding from the Sun are composed, like all other oscillations, of an electric vector, varying periodically with time and place, and of a similar magnetic one. Therefore the electro-magnetic streams of the Sun must act upon the magnetic condition of the Earth. In this connection we must take into account the fact that the magnetic vectors of the Sun's streams make very different angles with the magnetic vector of the Earth at different times, and that therefore the processes going on in the Sun are affected very differently by the various elements of terrestrial magnetism.

Since it has been demonstrated that electro-magnetic radiation is very closely related to the radiation of light and heat, there can no longer be any doubt that this also will play a great part in astro-physics.

STARS HAVING PECULIAR SPECTRA.*

M. FLEMING.

An examination of photographs of stellar spectra recently received from Arequipa, Peru, taken under the direction of Professor S. I. Bailey, and forming part of the Henry Draper Memorial, has added the objects of interest given in the following table to the list of those already known. The designation of the star is given in the first column, and is followed by its approximate position in right ascension and declination for 1900. The catalogue magnitude is given in the fourth column and a brief description of the spectrum in the last column.

Design.	R. A. 1900		Dec. 1900		Mag.	Descr.
	h	m	°	′		
A.G.C. 6519	5	31.7	— 25	48	8	Type IV.
D.M. — 29° 2538	5	47.2	— 29	19	9.3	Type III, hydrogen lines bright.
A.G.C. 8670	6	51.3	— 42	14	6.7	Type IV.
B.D. — 10° 1786	6	53.2	— 10	38	7.3	F line bright.
A.G.C. 13554	9	51.6	— 57	15	8½	Type V.
A.G.C. 13665	9	56.7	— 59	44	7¾	Type IV.
—— ——	10	6.1	— 62	5	—	Type V.
—— ——	10	14.4	— 62	9	—	Type V.
—— ——	10	22.9	— 58	8	—	Type V.
A.G.C. 19745	14	29.5	— 42	56	8½	Type IV.

D.M. — 29° 2538 has a photographic spectrum of the third type having also the hydrogen lines bright. Measures of the brightness of this star on photographs taken October 15, October 21, November 3, 1889; December 8, 1892; and March 18, 1893, give the magnitudes 9.4, 9.6, 10.0, < 11.4, and 7.9 respectively, thus proving its variability.

A.G.C. 13554, and the stars whose approximate positions for 1900 are in R. A. 10^{h} $6^{m}.1$, Dec. — 62° 5′, R.A. 10^{h} $14^{m}.4$, Dec. — 62° 9′, and R. A. 10^{h} $22^{m}.9$, Dec. — 58° 8′, have spectra of the

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* Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

fifth type, consisting mainly of bright lines, and these added to those already announced increase the known number of these objects to fifty-five. The galactic longitudes of these stars are 248° 43′, 253° 0′, 253° 51′, and 252° 42′, and their galactic latitudes — 2° 19′, — 5° 14′, — 4° 46′ and — 0° 46′ respectively.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., September 12, 1893.

THE SPECTRA AND PROPER MOTIONS OF STARS.*

W. H. S. MONCK.

I had hoped to be able to contribute a further paper dealing pretty fully with the spectra and proper motions of stars but want of time has hitherto prevented me. Some months ago, it occurred to me that there was possibly a mistake in the *Draper Catalogue* as to the spectra of certain stars with considerable proper motion which were described as Sirian; and on communicating my doubts, Professor Pickering had the spectra re-examined and in the kindest manner sent me a complete list of his results with liberty to publish them. The result was that the proportion of these stars which passed over to the solar class was even larger than I had expected. The readers of ASTRONOMY AND ASTRO-PHYSICS will very probably wish to see the details and to correct their copies of the *Draper Catalogue* accordingly. They are as follows (when two kinds of spectra are mentioned, the meaning is that the true spectrum is intermediate between them):

Number in Draper Catalogue.	True Spectrum.	Number in Draper Catalogue.	True Spectrum.	Number in Draper Catalogue.	True Spectrum.
124	G–H	3573	F	6828	F
236	F–G	3645	F	6864	F
511	F	3840	F	(7188	A–F)
607	F	3850	F	7539	F
707	F	4207	F	8288	G
892	F	4229	F–G	8578	K
899	F	4495	F	8656	I
1195	F-G	5081	F	(8726	A-F)
1267	G	5243	G	8792	K?
1287	F-G	5379	F-G	8865	F
(1583	A–F)	5469	F	9028	F
1726	F	5624	E–G	9163	G–H
2078	F-G	5692	F	9166	G–H
2476	F	5762	F	9200	F-G
2692	G	5924	G	(9842	A-F)
2824	F	6156	F-G	9938	F
(3435	A-F)	6159	F	10071	F
3446	F–G	(6176	A–F)	10134	H
3569	F–G	6802	F		

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* Communicated by the author.

More than one-half of the stars about whose spectra I inquired on account of their large proper motion appear in the foregoing list. Most of them were so faint that astronomers had already been cautioned against relying on the spectra given in the *Draper Catalogue*. Still I hardly expected that 60 per cent of the stars in my list would pass from one class to the other. Among those which thus pass over is the solitary star with spectrum B whose proper motion appeared to be considerable. Its true spectrum is F.

I re-examined the stars in the *Cincinnati Catalogue* whose spectra I had been able to identify in the *Draper Catalogue*—making these corrections. The revised numbers were the following: Capellan 275, Arcturean 157, Sirian 42. There were 5 stars of the Antarian type, 5 intermediate between Sirian and Capellan and 3 between Capellan and Arcturean. None of the Sirians, as already noticed, are of the type B.

I also submitted a list of Capellan stars which from their magnitudes and small proper motions I suspected to be really Sirians. In this instance, however, the spectra given in the *Draper Catalogue* were in the great majority of instances confirmed. The most noteworthy exception is β Orionis (or Rigel) whose spectrum is not F but B. Others which pass to the Sirian class are *p* Tauri, 42 Aquilæ, 1 Camelopardi, μ Sagittarii, 59 Piscis, 55 Cygni, $f_B{}^1$ Cygni, 18 Aquarii, 4 Pegasi, 18 Pegasi (B), 26 Cephei and *c* Piscis. It seems clear that there are several fairly bright Capellan stars whose proper motion is very small. This may arise from their motion being nearly in the same direction with that of the Sun, in which case they may have sensible parallaxes notwithstanding their small proper motion. At present we can only conjecture; but I recommend all fairly bright stars with the spectrum F to the attention of parallax-hunters.

ON THE APPLICATION OF DOEPPLER'S PRINCIPLE TO THE MOTION OF BINARY STARS AS A MEANS OF IMPROVING STELLAR PARALLAXES AND ORBITS, AND AS AN ULTIMATE MEANS OF TESTING THE UNIVERSALITY OF THE LAW OF GRAVITATION.*

T. J. J. SEE.

It is well known that the orbital revolution of binary stars does not enable us to decide as to the law of attraction govern-

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† Read before the Section of Astronomy, Chicago Academy of Sciences, Oct. 3, 1893.

ing their motion. In the planetary system the demonstration of the law of gravitation rests upon the laws of Kepler, which are found by observation to be very exactly fulfilled by the motion of the planets round the Sun. If the law of Newton did not hold with the greatest exactness, the effects would soon become very sensible in the motion of the perihelia of the planets;* and since (with the exception of Mercury, the anomalous motion of whose perihelion can be otherwise explained) actual observation does not disclose any such irregularities in the planetary motions, we may confidently believe that in our system the law of Newton is rigorously the law of nature.

In the stellar systems, however, the case is different, as observation merely shows:—

(1). That the apparent orbit of the companion is an ellipse;

(2). That the apparent radius vector describes equal areas in equal times.

It is found by observation that the principal star is not generally in the focus of the apparent orbit, and hence we cannot infer the existence of the law of gravitation.

But since the areas described by the radius vector are proportional to the time, we may infer that the motion is in a plane, as is indeed observed to be sensibly the case in the system of 42 Comæ Berenices, whose orbital plane passes approximately through the Sun. From this it follows that the force is central, but as many other forces besides Newtonian attraction can cause the companion to describe an ellipse, we can demonstrate the existence of the law of gravatation only by showing that the central star is in the focus† of the real ellipse, which requires us to know the inclination of the orbit.

In determining double star orbits it is customary to assume the operation of the law of gravitation, and the data of observation are then sufficient to enable us to find the elements of the real orbit. But as we thus employ the law of gravitation in deriving the inclination and other elements of the orbit, we cannot regard the inclination as independently known. Hence we must resort to the spectroscopic application of Döppler's principle to the relative motion of the two stars in the line of sight, as a means of testing the inclination derived from the theory of gravity. The relative displacement of the spectral lines of the two

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* *Mecanique Celeste*, Liv. II, ch. I, § 6.

† See the article of Professor A. Hall in Gould's *Astronomical Journal*, Vol. VIII, No. 177; also Tisserand's *Mecanique Celeste*, tome I, ch. I; or the writer's small monograph "On the Law of Attraction in the Stellar Systems" (Berlin, 1890).

stars will give the relative motion of the companion in the line of sight, freed from the effects of the proper motion of the system in space as well as from the effects of the motion of the Earth and Sun.

Thus, suppose the companion to be moving in its orbit near the ascending or descending node. It will then have a relative motion towards or from the Earth equal to

$$x = v \sin i,$$

where v is the velocity in the orbit, and i the inclination of the plane of the orbit to the tangent plane of the heavens. For any other point than the node the component of the motion in the line of sight would be

$$x = v \sin i \cos u$$

where u is the argument of the latitude.

Now if we take a system which is highly inclined like α Centauri, we see that $\sin i$ is very large and hence nearly the whole motion at the nodes will be towards or from the Earth. A simple calculation shows that the velocity of the companion of α Centauri varies from 5.6 to 18 kilometres (*i. e.* 3.5 to 11 miles) per second. At the ascending node the velocity in the line of sight will be at least 15 kilometres per second, and as the stars are about 9″ apart, this motion could easily be detected by modern spectroscopic apparatus. In case of α Centauri, the relative motion of the companion in the line of sight will never be much less than 5 kilometres per second, and hence if this star were accessible it would be particularly well suited for testing the law of gravitation. The great difficulty with most stars will lie in the unknown or inaccurate parallax and in the closeness and inequality of the components.

If we take the case of 70 Ophiuchi, we find by means of Krueger's parallax (0″.162) and Burnham's orbit, that the average orbital velocity of the companion is about 9.5 kilometres per second. The average relative velocity of the companion in the line of sight will be about 8.5 kilometres, which ought to be detected by modern apparatus. The practical difficulty of detecting this motion would be increased by the inequality of the components, but this obstacle may not prove insurmountable.

Now to test the law of gravitation it is only necessary to compare the spectroscopic velocity in the line of sight with the velocity computed from the theory of gravitation by means of the ascertained parallax of the system. If the results agree, we may conclude that the law of gravitation is as accurate as the other elements entering into our calculation. If the results disagree to a marked extent, we may look for some error in the parallax of the system (this is the weak point), or in the elements of the orbit, or lastly in the law of gravitation.

Thus spectroscopic observations will serve to check the parallaxes of binary systems and to improve their elements, as well as to confirm the law of gravitation. It is to be hoped that some great Observatory will take up the spectroscopic investigation of the motions of binaries and their parallaxes. These lines of research may confidently be expected to greatly increase our knowledge of other systems in space.

THE UNIVERSITY OF CHICAGO,
1893, Aug. 31st.

AN ABSOLUTE SCALE OF INTENSITY FOR THE LINES OF THE SOLAR SPECTRUM AND FOR QUANTITATIVE SPECTRUM ANALYSIS.*

L. E. JEWELL.

A "long felt want" in spectroscopic work has been a scale of intensity, which should be reasonably accurate, and constructed upon some rational sort of a basis.

During the last few years while engaged upon the determination of the wave-length and character of all the lines in the solar spectrum, (a work carried on at the Johns Hopkins University under the supervision of Professor H. A. Rowland), I have often felt the need of some definite sort of a scale for the estimation of the intensity of the solar lines, while the inaccuracy and the arbitrary and unsatisfactory character of eye estimates has continually become more evident.

It was while in this state of mind that in January, 1892, Professor Harrington, chief of the U. S. Weather Bureau, wrote to Professor Rowland to see if an investigation of the "*rain band*" could not be undertaken, upon a large scale and by photographic means, at the physical laboratory of the Johns Hopkins University.

I made the investigation, and the scale of intensity which forms the subject of this paper was one of the results.

In making observations upon the "rain band," comparisons of intensity were made between solar and water-vapor lines, of nearly equal intensity, and as near to each other as it was possible to find satisfactory lines.

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* Read at the Congress of ASTRONOMY AND ASTRO-PHYSICS, Chicago, August, 1893.

This was the only method at all practicable, but to get out of this any result which should be other than mere guess-work, it becomes necessary to in some way calibrate both the solar and water-vapor lines which were used in the comparisons. The plan adopted was to make a photographic scale, consisting of a series of lines formed by photographing the image of a narrow slit, the exposures being related to each other in geometrical ratio, the ratio adopted being the square root of two, so that every other line would be related in the ratio of 1, 2, 4, 8, etc.

A scale thus constructed as a trial was found to have its lines not sufficiently like those of the solar spectrum to make comparisons of any value, and the plan adopted to correct this defect was to place in front of the photographic lens a wire screen sufficiently fine to produce slightly diffuse lines, but not so fine as to produce troublesome diffraction bands.

In this way a scale was produced in which the lines had nearly the appearance of the better class of solar lines, and which varied in intensity according to some rational and definite rule.

The first complete scale thus produced has a number of defects which would be expected in any first production, but it has answered the purpose so well, that, taking into consideration the difficulties in producing a more perfect scale, and not having some of the apparatus necessary to the production of a more satisfactory one, and being pressed for time, I made the calibration of the comparison lines used in the investigation with the original scale.

The principal defects referred to are, first, an uneveness in the width and consequently in the intensity of the different portions of the same line, due to defects in the slit used; and secondly one due to the turning of the camera upon its axis horizontally, in order to place the image of the slit in its proper place upon the photographic plate, thus introducing an error caused by the field of the photographic lens being unequally illuminated. This can be avoided by moving the photographic plate across the field. A satisfactory scale can be constructed by using a slit, made by cutting with a thin, sharp, knife edge, a straight narrow line through the film of a blackened photographic plate; or by photographing a wire stretched against the sky or any other bright even background, and using the resulting negative as a slit. The intensity ratio of the scale can be made anything that is desired by properly adjusting the development and exposure ratio.* We thus have a scale which resembles the better class of solar lines pretty closely and which can be relied upon to have the intensity ratio of the scale a *constant*, for this is the important feature of a scale and not the numerical value of the ratio. This is not strictly true but for the object for which the scale is to be used, and considering the range of intensity likely to be used, it is closely approximate. Considering the deposite of silver in the lines of the photographic scale to have been directly as the length of exposure, the ratio of intensity will be according to the law of absorption, which is slightly different from a geometrical series. As this matter is carefully gone into in a paper to be published by the U. S. Weather Bureau I need say nothing farther than that the law governing the intensity of the lines in the scale and the law of absorption for lines such as those in the atmospheric spectrum are the same, the numerical value of the ratio only being different. Measurements made by the scale can be reduced almost as readily as though the intensities of both kinds of lines varied according to a geometrical ratio. The numerical value of the intensity ratio or the gauge of the scale can be determined by the bolometer or by other means, but a much more important thing is to determine its value in terms of the absorption produced by different quantities of the substance, the absorption lines of which it is desired to investigate.

In an investigation of the atmospheric lines, a quantitive calibration of the scale can be made, by determining the amount of material through which the sunlight has passed at the time the observations for calibrating the scale are made.

The oxygen constituent of the air offers a ready means of doing this, as it varies little from day to day, and the amount of oxygen (for preliminary work the whole atmosphere may be considered as of constant constitution) traversed by the sunlight at different elevations of the Sun has been calculated by Forbes and Bouguer.

In observing, the scale is placed in the focus of the spectroscope, and the line which it is desired to measure is brought between the two lines of the scale which are nearest to it in intensity.

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* A scale constructed in this way, but using a small round hole instead of a slit in front of the source of light, and with the screen in front of the photographic lens as before, might form a very useful scale for the determination of the photographic magnitudes of stars, or rather the inverse of such a scale. By the proper adjustment of the screen the appearance of the photographic image of a star could be imitated very closely indeed, and the intensity ratio of the scale could be made anything desired.

A scale constructed upon this principle could also be made very useful in the visual determination of magnitudes.

It might be supposed that measuring under different conditions with different gratings and in different orders of spectra, might cause endless confusion and difficulties, but this is not the case.

The scale intensity of a line depends upon the *quality* of the spectrum produced by a grating, as regards definition and amount of diffuse light, also upon the dispersion used and upon the width of the slit, and though the measurements made upon a series of lines under different conditions will not give the same values in each case yet the measurements are strictly comparable as the differences are constants which depend upon the width of slit, quality of spectrum, and dispersion used, so that they can be reduced to whatever conditions are taken as standard.

In this way the laws governing the absorption of light by gases can be studied and the intensity of the lines of the solar spectrum can be determined upon a scale which really means something, which can be used for quantitative spectrum analysis, and which may justly be considered an absolute scale, as any errors to which it may be subject can be determined, and allowed for. It can be used for both eye and photographic determinations. In the latter the scale can be placed in contact with the photographic plate and an exposure made just as in photographing the solar spectrum, the result being the lines of the scale along with the solar lines. A better way for most purposes, however, would be to photograph the solar spectrum on one part of the plate, and then with the exposed portion protected, photograph the lines of the scale upon the unexposed portion of the plate, using the light of the solar spectrum but interposing a strip of ground glass to diffuse the light and make the background more uniform.

Additional exposure should be given when photographing the lines of the scale in order to make the background of the same intensity in both strips, and this ratio should be followed in all determinations with the same apparatus in order to have the comparisons comparable, except that where there are many lines in the part of the spectrum to be measured, sufficient additional exposure should be made to make up for the loss of light caused by the lines, and to make the background of the two strips of equal intensity. This only applies where the ground glass is used.

A negative of the scale can be used for photographic determinations of the intensity of the metallic lines.

To show the results of quantitive measurements, I give, by permission of Professor Harrington some few results obtained in the investigation of the "rain band."[*]

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[*] To be published by the U. S. Weather Bureau.

Curve 3 represents the amount of atmosphere passed through by sunlight at different altitudes of the Sun, where unity equals the amount passed through with the Sun overhead. Curve 1 is the intensity curve of the oxygen lines as measured upon the scale where unity represents the intensity of the lines with the Sun overhead. In like manner curve 2 represents the intensity curve of water-vapor lines for winter and curve 4 for summer, where in each case unity represents what would be the intensity with the Sun overhead. It is evident that curves 1 and 3 are related in some way, and a study of the curves would show that the relation is the same as that of two geometrical series with different ratios. Curve 1 is what would be produced were the ratio of absorption the same as that of the material producing absorption, and if the intensity ratio of the scale used were about 1.8 instead of 1.414.

The curve is also what would be produced were the intensity ratio of the scale 1.414 and the absorption ratio 1.51 instead of 2 for double the amount of absorbing material. The intensity ratio of the scale may be slightly larger than 1.414 but is certainly not as large as 1.8, consequently if sunlight passes through two masses of absorbent gas (oxygen in this case) one of which is double the other, the ratio of the absorption will be less than two, and this is what would have been expected theoretically.

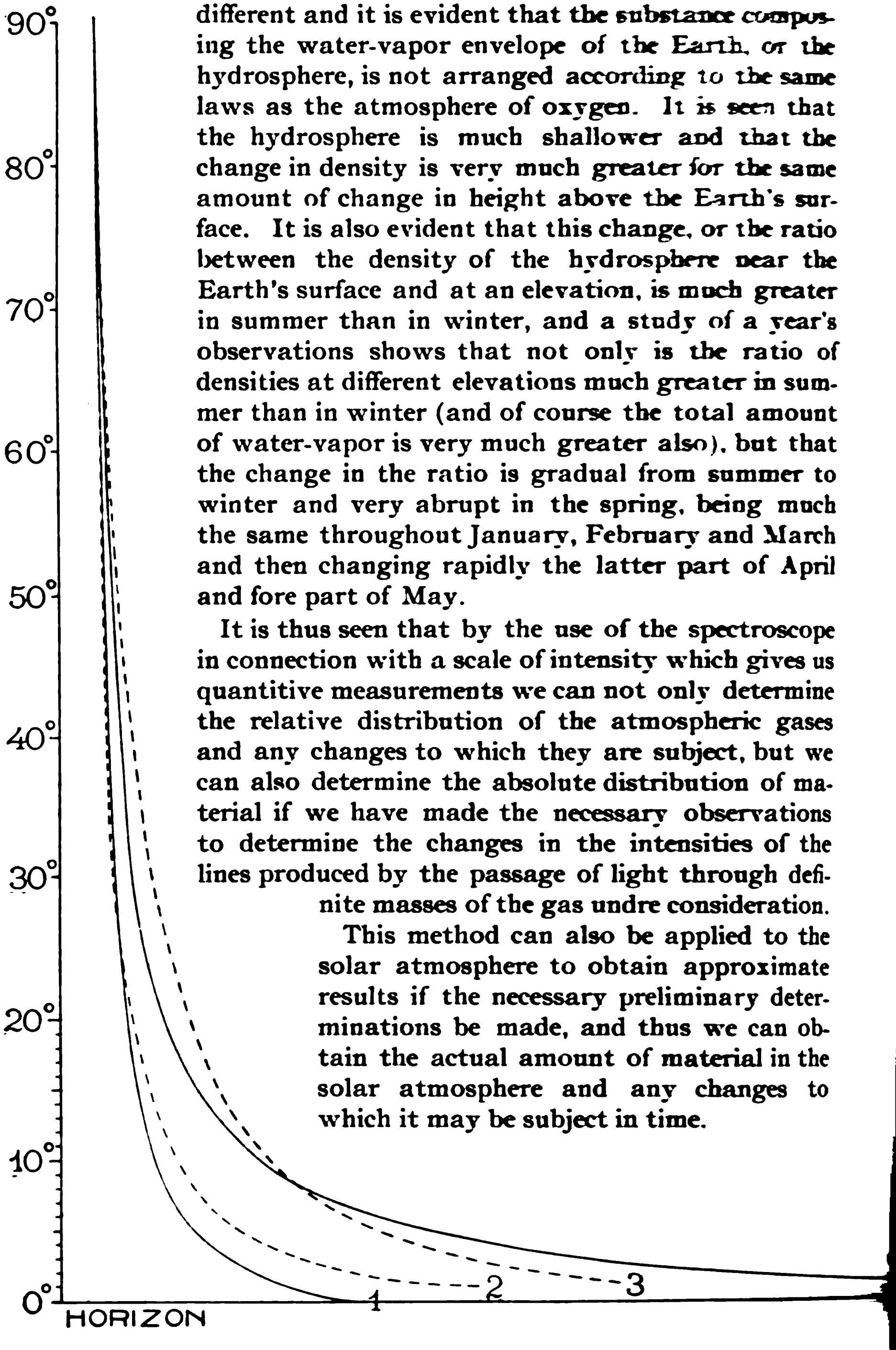
The scale has never been calibrated for the intensity ratio of the series of lines composing it, consequently I can not give the absorption ratio for oxygen, but for the present purposes this is not necessary as we have already made a *quantitive* calibration of the scale, and if we raise all the results obtained with the scale to the 1.8th power, we will obtain results which correspond to quantities of material producing the absorption.

Thus as an instance with the Sun overhead, the first line in the tail of the α group will read 4 on the scale used, and this corresponds to a beam of sunlight of 1 centimetre square section passing through 1.033 kilogrammes of air or 0.2356 kilogrammes of oxygen. When the Sun is on the horizon, the line will read 18.6 on the scale used. This means that the line is 7.8 times as intense in scale value, and raising this to the 1.8th power we obtain 38.57, or in other words, the sunlight has passed through 38 times as much material as when overhead, or a beam of one square centimetre section has passed through 8.88 kilogrammes of oxygen.

If we examine curves 2 and 4, we see that the form of curve is different and it is evident that the substance composing the water-vapor envelope of the Earth, or the hydrosphere, is not arranged according to the same laws as the atmosphere of oxygen. It is seen that the hydrosphere is much shallower and that the change in density is very much greater for the same amount of change in height above the Earth's surface. It is also evident that this change, or the ratio between the density of the hydrosphere near the Earth's surface and at an elevation, is much greater in summer than in winter, and a study of a year's observations shows that not only is the ratio of densities at different elevations much greater in summer than in winter (and of course the total amount of water-vapor is very much greater also), but that the change in the ratio is gradual from summer to winter and very abrupt in the spring, being much the same throughout January, February and March and then changing rapidly the latter part of April and fore part of May.

It is thus seen that by the use of the spectroscope in connection with a scale of intensity which gives us quantitive measurements we can not only determine the relative distribution of the atmospheric gases and any changes to which they are subject, but we can also determine the absolute distribution of material if we have made the necessary observations to determine the changes in the intensities of the lines produced by the passage of light through definite masses of the gas undre consideration.

This method can also be applied to the solar atmosphere to obtain approximate results if the necessary preliminary determinations be made, and thus we can obtain the actual amount of material in the solar atmosphere and any changes to which it may be subject in time.



In constructing an intensity scale for the solar spectrum, it would probably be well to take as unity the first line in the tail of the α group when the Sun is overhead, or in other words the value of the line in question for one atmosphere.

Of course in measuring the intensity of a line neither the width nor relative darkness of the line is to be considered alone, but the whole effect or the integral of absorption.

In a determination of intensity it is best to avoid as far as possible eye estimations of differences of intensity; but where two lines are the same or very nearly the same intensity the eye is pretty reliable, consequently a scale should have the ratio between the intensities of adjacent lines as small as the eye can readily perceive.

The lines of the solar spectrum or of the different bands of oxygen furnish sufficient material for either the testing or calibration of a scale if their intensities were once satisfactorily determined.

MARIETTA, Ohio, Aug. 18th, 1893.

HELIOGRAPHIC LONGTIUDES REFERRED TO THE SOLAR MAGNETIC PRIME MERIDIAN.*

FRANK H. BIGELOW.

Heliographic longitudes for Sun spots and other solar phenomena have been referred to the prime meridian established by Carrington as the result of his Red Hill observations. It assumes that the period of rotation of the sun-spots at a certain latitude is the same as that of the body of the Sun, and that the solar equator revolves more rapidly, the reason for this being unknown. There has been no way to test these assumptions, and consequently the system of longitudes proposed by Carrington has been in use for forty years, adopted into astronomy as he gave it. The recent application of terrestrial magnetic variations to the state of the permanent magnetism of the Sun,† gives us, however, an opportunity to view the problem in a new light, and questions the soundness of Carrington's position.

In order to state clearly the two sides to the argument, the usual method of computing heliographic longitudes will be briefly given, in a notation which agrees with the symbols of my preceding papers.

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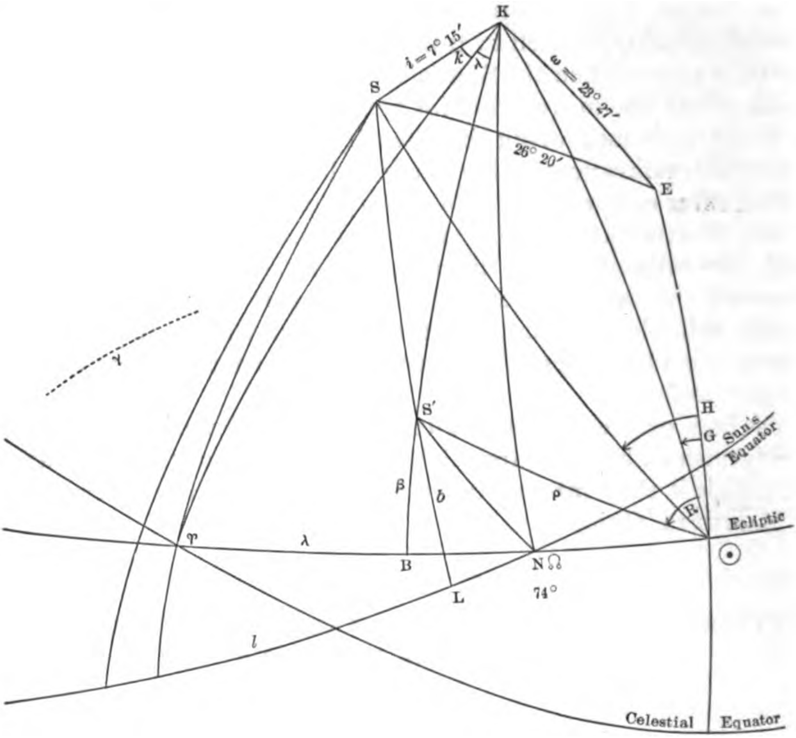
* Communicated by the author, by permission of the Chief of the Weather Bureau.

† See ASTRO-PHYSICS, Oct., 1893, and the *American Meteorological Journal*, Sept., 1893.



K = Pole of Ecliptic, S = Pole of Sun's Equator, E = Pole of Earth's Equator, Vernal Equinox at sign Aries, N = Longitude of Ascending Node of Sun's Equator on the Ecliptic = 74°, ⊙ = Center of Sun's disk as seen from the Earth = Heliocentric Longitude 180 + ⊙. G = Auxiliary Angle E⊙K, H = Auxiliary Angle E⊙S. From sign Aries to B = λ Heliocentric Longitude, and BS' = β Heliocentric latitude of spot S'; L = NL, Heliographic longitude of the Spot S'.

Given the Position Angle, R = K⊙S', and distance from centre of disk ρ (corrected each), *to compute l, b.* K⊙ = 90°. B⊙S' = 90° − K⊙S' (direction of position angle NE SW), and ⊙S' = ρ in measured linear distance.

$$\sin \odot S' = \frac{\odot S'}{\text{Sun's semi-diameter}}.$$

$\sin BS' = \sin \odot S' \sin B\odot S'.$
$\tan B\odot = \cos B\odot S' \tan \odot S'.$
$BN = N\odot - B\odot$
$N\odot = 180 + \odot - N$ (where ⊙ = longitude of the Sun at date).
$\cos NS' = \cos S'B \cos BN.$
$\cos S'NB = \cot NS' \tan BN.$
$S'NL = S'NB + 7° 15'$
$\sin S'L = \sin b = \sin NS' \sin S'NL.$
$\sin NL = \sin l = \tan S'L \cot S'NL.$

Carrington took for his prime meridian that which passed through the vernal equinox for 1854.0 that is from S to sign Aries; for the period of rotation, sidereal 25.38 days or synodic 27.27526 days, equivalent in mean daily motion to 14°.1844 = 851′.064. This prime meridian comes to the central meridian on such dates that Nov. 9, 1853, may be adopted as the beginning of revolution No. 1, and the direction of reckoning longitudes being in that of the rotation of the Sun on its axis, this meridian will be in longitude 14°.1844 at the beginning of the 2° day, 28°.3688 at that of the third day, etc., apparently to the west of the centre of the disk. Therefore the longitude of the prime meridian from node,

$$l' = T \frac{360^\circ}{25.38},$$

where T is the number of days elapsed since the prime meridian is central. Finally the heliographic longitude of the spot from the prime meridian $= l - l'$.

The following table gives the result of the observations of Carrington and Spoerer for mean daily motion of the sun-spots in longitude at different latitudes.

Latitude.	Carrington's daily motion.	Sporer's daily motion.
°	′	′
0	867	881.5
2	866	874.3
5	864	861.6
7	861	858.6
9	858	853.6
12	854	851.9
14	850	843.5
16	847	837.5
18	842	832.9
21	837	832.1
25	830	827.0
30	818	823.9

The mean daily motion 14°.1844 (Carrington) therefore corresponds to latitude 13°.5, and 14°,2665 (Spoerer) to latitude 10°.5 and they represent the *average rate of motion of the whole body of Sun-spots.*

Carrington's motion at the equator is 867′.
Spoerer's " " " " " 881′.5.
Faye's " " " " " 863′.
Tisserand's " " " " " 858′.

No arguments have ever been presented to show that the adopted rotation corresponding to latitude 10° — 13° is that of the body of the Sun, rather than the other rates deduced for the equator itself. On the face of the problem all the theoretical arguments are in favor of the equatorial rate, since, as is so well known in meteorology from the work of Ferrel, Helmholtz, Oberbeck, and many others, a rotating spherical body having fluid or gaseous constituents will set up surface currents, those at the equator having nearly the same rate of angular motion as the solid nucleus, those at 10° — 15° north or south latitude having a steady anti-rotational drift relatively to the equator. Hence it is natural to suppose that the sunspots do rotate more slowly than the equator, being transported in this anti-rotational current, of which we see an example in the tropical trade winds of the Earth.

I have already announced my result, the details of which will be published soon, for the angular motion of the permanent magnetic system of the Sun, which is supposed to reside in a rigid nucleus. Since the magnetic output leaves the Sun near the the magnetic poles and therefore within a few degrees of the poles of rotation, the two axes being separated by about 4½°, we must ascribe the resultant motion to the polar regions of the Sun. This angular velocity is 868′.758, and it will be observed that it is nearly the same as that adopted by Carrington, 867′, the mean value of the authorities quoted being 867′.4. The result of the magnetic work depends upon the total mass of observations of the magnetic and meteorological observatories of Europe and the United States, covering the period 1878 to 1892 inclusive, and has the same scientific value as the observations of sunspots, since the computations can be verified at any time. This close agreement between the polar and the equatorial daily motions is a strong argument in favor of the view that the sunspots flow anti-rotationally past the equator, the true period of solar rotation being represented by the values 867′ or 868′.

The epoch chosen for the magnetic ephemeris is 1887, June 12.22, and corresponds to the instant, Greenwich mean time, when the solar meridian passing through the south coronal or magnetic pole is central on the disk. There has long been a need in solar physics that a permanent physical meridian be localized on the Sun to which solar phenomena can be referred. This adopted meridian is analogous to a plane on the Earth through the geographical pole and the magnetic pole of North America (negative, the south coronal pole of the Sun being also negative), and using it for the plane of reference, instead of Greenwich. The motion of magnetic poles, if any exists, would be an objection to the permanent verification of such a meridian, but the one passing through such a pole at an epoch, would be the proper basis for investigating the problem of the secular variation.

It will be found that Carrington's prime meridian and the proposed magnetic meridian coincided with each other on June 19.16, 1883, October 12.76, 1886, and February 5.15, 1889, G. M. T., the interval being 1211.35 days, from which other dates o-coincidence can be computed.

It would seem more natural also in the classification of solar phenomena, to adopt an antirotational system of longitudes, as on the Earth, the west longitudes being positive. Therefore the longitudes for the beginning of each day, Greenwich mean noon, counted on the surface of the Sun in a direction opposite to Carrington's, will be as in the following table.

LONGITUDES ON THE SUN REFERRED TO THE MAGNETIC PRIME MERIDIAN THROUGH THE SOUTH CORONAL POLE.

SYNODIC DAILY MOTION 13°.4936.

Days.	Degrees.	Days.	Degrees.	Days.	Degrees.
0	0°.0000	10	134°.9360	20	269°.8720
1	13.4936	11	148.4296	21	283.3656
2	26.9872	12	161.9232	22	296.8592
3	40.4808	13	175.4168	23	310.3528
4	53.9744	14	188.9104	24	323.8464
5	67.4680	15	202.4040	25	337.3400
6	80.9616	16	215.8976	26	350.8336
7	94.4552	17	229.3912	27	364.3272
8	107.9488	18	242.8848		
9	121.4424	19	256.3784		

The tabulation of solar phenomena in this way is perfectly simple, it being necessary to reduce the observed position at a given instant of time to the central meridian of the date, and then tabulate the same by the longitudes of the synodic rotation.

The dates for the beginning of the coronal magnetic periods are derived from the epoch 1887, June 12.22, with period 26.68 days.

DATE OF BEGINNING OF FIRST PERIOD IN EACH YEAR.

1880	Jan.	25.54	1890	Jan.	1.02
1881	Jan.	6.38	1891	Jan.	9.54
1882	Jan.	14.90	1892	Jan.	18.06
1883	Jan.	23.42	1893	Jan.	25.56
1884	Jan.	5.26	1894	Jan.	7.32
1885	Jan.	12.78	1895	Jan.	15.84
1886	Jan.	21.30	1896	Jan.	24.36
1887	Jan.	3.14	1897	Jan.	5.20
1888	Jan.	11.66	1898	Jan.	13.72
1889	Jan.	19.18	1899	Jan.	22.24

I found it impossible to obtain any periodic result from Sunspots, auroras, magnetic storms, and meteorological variations, when using the sunspot period of Carrington, but on the other hand all these phenomena reduced to a consistent inter-related system when the equatorial rate was laid at the basis of the investigation. It will be most interesting to know whether the Sun does not dispose the spots, the faculæ, the prominences, in such habitats as correspond to the magnetic meridians, whose relative strength has already been indicated in the publications referred to above.

THE PHYSICAL CONSTITUTION OF THE SUN.*

WALTER SIDGREAVES.

The year 1859 has become memorable in the history of astronomy, as the epoch of a new departure in the science of the heavens. Newton had dimly forecasted it from his great discovery of the composite nature of ordinary light; Wollaston had divined the secret of the right analysis of the Sun beam, when in 1802 he substituted the straight slit for Newton's round hole in the shutter; and Fraunhofer had introduced the solar hieroglyphics to the speculation of astronomers in 1814, when he gave them his map of some 600 dark lines crossing the solar spectrum. But it was not until 1859, after 45 years of waiting amidst the puzzled conjectures of physicists, that the meaning of the lines was clearely deciphered, and the instrument which showed them was proved, by the classical experiments of Kirchhoff and Bunsen, to be the far-reaching analyzer of the chemical laboratory.

The first and fundamental lesson of the new teaching was what may be termed the specific radiation and selective absorption of matter in the gaseous state, as opposed to its universal radiation in the liquid or solid state at incandescence. The unquestioning acceptance of this principle. at its first enunciation by the eminent professors of Heidelberg, stamped it with the mark of truth. Its simplicity, and its perfect harmony with the growing insight into the nature of heat and light left no room for hesitation. In the more attenuated and delicate form of existence, which exhibits the properties of a gas, the molecular vibration is incapable of exciting, in the universal ether, any but its own periodic vibrations; while in the grosser form of the liquid or the solid state, its vibrations, according to their energy, excite indiscriminately every degree of oscillation frequency.

The immediate deduction from this principle was the broad

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* Communicated by the author.

statement of the physical constitution of the Sun; that it must be a solid ball, or a liquid sea at white-heat incandescence, surrounded by a heated gaseous atmosphere containing the vapors of many metallic substances. This statement of the Sun's condition held its place amongst the accepted certainties of celestial physics until the year 1865, when it received a modification which in no way contravened the principle of Kirchhoff and Bunsen. It was well known that the bright illumination of the candle flame or of the coal gas flame was due to the incandescence of a cloud of small carbon particles floating in the heated, gaseous envelope of the flame; and this form of the solar photosphere came into favor in the year 1865. Father Secchi seems to have been the first to suggest it in January, 1864;* but the novel conception of its origin as expounded to the Academy of Sciences in 1865, by M. Faye, together with the opposite account of its formation supported by the Kew observers, brought the subject before the judgment of solar physicists. The two theories of the cloud formation appeared almost simultaneously. The Kew observers had their proposition ready for the press at the time of M. Faye's publication in the *Comptes rendus*. But the two authors of the modification of Kirchhoff's photosphere had moved on different lines. M. Faye, following up a consideration of the effects of the intense heat of the interior solar mass, concluded that matter, there, must be in an ultra-chemical condition, in a primordial state or state of dissociation, incapable of energetic or universal radiation; and that there must be a limiting sphere where association and condensation would be continuously exchanging with vaporization and dissociation. The Kew observers on the other hand considered only the atmospheric state of the solar orb; and, reasoning possibly from our own climatic action, concluded also that there must be continuous exchanges between condensation and vaporization. Thus both schools arrived at the same cloud formation of the photosphere from opposite startings; the French savant rising to it from the interior condition of the Sun, the English descending to it from that of the outside surroundings.

The formation of spots upon the surface of the Sun naturally became the test of the rival methods. Each school following its own line of thought derived the origin of the spot from its own starting point. Faye's conception of these was a rent in the luminous cloud by an outburst of heated gases clearing away the incandescent condensations and exposing to our view the interior

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* *Bull. Meteorologico*, Jan. 1, 1864, p. 4.

feebly radiating dissociated matter; while Dr. Balfour Stewart, with his colleagues de la Rue and Lowey, attributed the dark areas to the cooler gases descending upon the photosphere. Both authors accepted ascending and descending currents in connection with spot-formation; but from the beginning the issue between them was clearly lined between the two currents, or as Mr. Lockyer has it, between a heat too great and a heat too little for a radiative energy equal to that of the photosphere.

Faye's hypothesis was in itself a tempting one. The intense heat of the Sun seemed to exclude the possibility of matter holding together in chemical union against so great a separating energy. And matter in this primitive condition would be incapable of luminous radiation; so that a dark nucleus was provided for the background of a hole in the photosphere, to account for the spot. But here the theory broke down under Dr.. Balfour Stewart's remark that the principle of reciprocity of radiation and absorption would claim for the non-radiating solar nucleus a transparency which must show the white photosphere at the opposite side of the Sun, in place of the dark background required for the spot. It failed therefore to account for the spot, and so lost its *raison d'etre*. But independently of extrinsic tests of fitness, the theory seems to overreach itself intrinsically. We cannot differentiate between heat rays and light rays in denying the property of radiation to dissociated matter; and we cannot reasonably admit the property of communicating heat by contact in a mass which is unable to give off heat by radiation. A thermometer, if it could be introduced into the solar nucleus without passing through the fiery photosphere, and could be completly screened from the photospheric radiation by a perfect reflector, would show no change of temperature; for its surroundings could neither give nor receive heat. In other words the dissociation of a fragment of matter, entering into the solar nucleus becomes impossible, for the maximum temperature that can be imparted to it is that of the photosphere, which by supposition is below the the temperature of dissociation; and re-association is impossible, for dissociated matter can lose no heat.*

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† The writer does not deny either that dissociation is possible, or that dissociated matter is incapable of radiation and absorption. Both may be accepted and also the consequences enumerated below, without violence to reason.

1°. All the heat of dissociated matter is absolutely latent: dissociated matter cannot part with heat, it has its fill and can receive no more, it can only transmit what comes to it.

Corollary 1. The temperature of dissociation is the maximum temperature of matter.

We have left out of consideration so far, the internal pressure of the Sun's mass. It has an important bearing upon the physical aspect of the solar nucleus, if not upon its physical structure. The pressure effect upon the spectrum of gaseous radiation is now known to be a widening of the radiation lines; and this to such an extent that, at the great pressure in the interior of the Sun, the radiation energy must have a continuous spectrum. So that we have in a manner to return to the statement of Kirchhoff that the solar nucleus is either a glowing rock or a molten sea of fire, in as much as it may be the equivalent of either, in its white radiation. This is our nearest direct experimental test of Faye's theory, and its witness is against the dark nucleus: for whatever be the properties of dissociated matter, if it is contained within a fluid shell it must be subject to pressure, and to exclude the spectrum effect of pressure could only be, what Miss Clerke has called in another case, "an arbitrary expedient of theory."

The same conclusion, although not opposed to the misty photosphere, claimed by the Kew school, is not in favor of it; for the incandescent cloud of condensation would be rather a screen to the more energetic radiation of nucleus than itself the light distributer. But has it a place in solar meteorology? We venture the answer,—no. When we try to measure the intensity of solar radiation within its own atmosphere, by comparison with the heat experienced at our distance of over 90,000,000 of miles, we are forced to put the question: is condensation possible amidst those untold heats; and the answer comes with irresistible force that no metallic substance known to us can assume the vapor state anywhere in or near the solar chromosphere unless perchance under the chilling influence of expansion in eruptive disturbances.

A third explanation of spot-formation is that of the late Father

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Corollary 2. The potential energy of dissociated matter is very great, responding to its great latent heat.

2°. Dissociated matter can neither exert nor suffer pressure; for pressure fails together with ability to communicate heat by contact.

Corollary 1. Dissociated matter cannot be confined by associated matter, but permeates all forms of chemical structures.

Corollary 2. The temperature of dissociation is another critical temperature, at which matter escapes the grasp of pressure, as the vaporization of ether eludes it in the experiment of Cagniard de la Tour.

3°. Re-association is impossible: for dissociated matter cannot lose heat.

Finally dissociated matter cannot be called primordial, but is a final state. Its properties are not those of the solid, the liquid, or the gaseous state of chemical matter; but they are apparently those of the ubiquitous caloriferous and luminiferous ether. It is imperishable. It has no temperature. Its high potential energy may account for the enormous elasticity indicated by the velocity of light. It may be subject to changes of potential, analogous to the pressure and tension of mechanics, resulting in the phenomena of electrical discharges.

Secchi, communicated to Professor Newcomb's Popular Astronomy in 1877. In this paper the darkness is accounted for by the general absorption of the relatively cooler gases descending upon the photosphere, and this mode of stopping the light from the photosphere would be very acceptable as dispensing with the condensations which appear to us impossible, if it could be brought into harmony with the spectroscopic testimony upon the state of the gases. But the spectroscope bears witness against it. For general absorption begins under those conditions of pressure where selective absorption ceases; and the spectroscope shows that selective absorption in the line of sight to the spot is very pronounced. It is true that there is nothing in the nature of things to disprove the association of a feebler general absorption with a stronger selective absorption in gases under ordinary pressures. But the burthen of demonstration is on the other side; for selective and general absorption are opposed to one another, and what evidence we have from the spectroscope is against the admission of a general absorptive action by matter in the gaseous state. This evidence comes from the reciprocal action of radiation, in which we find the lines of specific radiation, corresponding to those of selective absorption, quite sharply defined, and consequently showing no increase of general radiation in the immediate neighborhood of its most active radiation; and we must suppose that if there were any general radiation by the incandescent gas, this would be stronger in the wave-lengths most nearly equal to those of its specific radiation.

M. Faye's latest theory, as set out in his graphic description of the solar whirlpools and cyclones, in "*l'origine du Monde,*" brings us no nearer the goal of our enquiry—a satisfactory cause of spot-darkness. The funnel-shaped depression produced by the gyratory motion set up in the photosphere could give the required darkness only in two ways: it might sufficiently reduce the depth of the photosphere in the direction of our vision to result in a relative darkness, if the author's original theory of a dark solar nucleus could be admitted: it would certainly draw down into it relatively cooler hydrogen, as the author has it; but the cooler hydrogen could stop the light only by reflection, by refraction, or by absorption; and of these, absorption only could claim consideration; but if absorption could be accepted as the stopping agent, we should prefer Secchi's theory, on the grounds that the disturbing energy is more probably amongst the greater than amongst the lesser heats of the solar furnace.

So far therefore in our search amongst the prominent theories of solar spot formation, we have failed to find a satisfactory cause of the darkness. Faye, in his original theory, struck at the root of the difficulty by removing the candle: he bored a hole through the luminous source, and so got rid of the light. The Kew school placed a cloud-screen of condensed vapors, cooled by radiation into space, to stop a part of the light; and Father Secchi adopted an absorption screen of the cooler descending gases. We have been unable to accept any one of these, and are left to seek the explanation either amongst the unknown capabilities of electrical action, or in the chilling effect of expansion already alluded to.

Electrical action has been suggested to more than one observer of the solar prominences. These fantastic and changing forms can hardly fail to recall the impression of electrical illuminations of rarified gases. But we are not at liberty to attribute effects to doubtful causes, until we have become in some way acquainted with their aptitude: and as yet we have no proof that electrical illumination is apt to exalt or degrade radiation, after the manner of an approaching or receding light-source, to account for the occasional distortions witnessed with the spectroscope. Electrical action increases the opacity of a cloud of minute condensations, and much of the darkening of a solar spot may be attributed to it, but Mr. Aitken's experiments* go far to show that the immediate effect of this action is not condensation, but a multiplication of smaller aqueous specks by the fracture of the larger drops: in other words that the immediate effect of electrical action is not darkness but an increased opaqueness of a screen already produced by another agent.

The alternative supposition is free from any imputation of impossibility, and has the strongest claims to represent the truth. We want a cooling source akin to Faraday's refrigerator when he succeeded in freezing mercury in a white hot crucible; and the chill of expansion seems to us the only possible agent of the kind in the big solar crucible. A solar eruption must owe all its developed kinetic energy to the pent up heat energy suddenly released by an external disturbance of the balance of pressure. The work done in expansion by lifting the superincumbent atmosphere would be great and all at the expense of heat in the expanding gases. In the lower levels of the outrush a cloud of metallic precipitations would form, stopping by reflection the photospheric radiation; while the uplifted masses would receive an increase of heat in the process, and would be placed at a position of advan-

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‡ Proceedings R. Soc. LI, p. 408.

tage for radiation into space, less hindered by absorption. These would be to our telescopes as luminous clouds, and their gaseous state would be shown in our spectroscopes. They would necessarily drift away from the centre of the eruption and the dark cloud below would then be revealed to us as a solar spot surrounded with faculæ.

This genesis of the spot and its attendant faculæ is in complete harmony with the observed details of its structure, and of its birth and growth: the dark area is below the photosphere, the faculæ are above the photosphere, and it is highly probable that the preparatory sign of a new spot is always a small bright patch of facula as the cradle of its infancy.

It is generally admitted that spots are real cavities in the solar photosphere, although not all observers have been able to verify the foreshortening effect upon the penumbra described by the Glasgow professor, Dr. Wilson. But it is at least a reasonable supposition that the dark space descends below the luminous surface of the Sun. This would be the region of released pressure or of rarefaction consequent upon the expansive eruption,—the region of chill and of precipitations,—where the cooler gases would augment the selective absorption, and the cloud of dark dust would partially screen the white photospheric radiation.

It is no less certain that the faculæ are at higher elevations, and that many of them extend to great heights. We cannot place much reliance upon mere appearances, as of faculæ crossing over or even diving into the cavity. The same appearance could be produced by more intensely glowing parts of the photosphere below the spot. But there is reason for saying that solar prominences are faculæ viewed in elevation, and in this picture it is the proper function of the eye to assign relative position. All observers of the solar prominences know that the finest displays of these fiery forms are always to be expected when the faculæ of a spot are turning over the solar limb; and the photographic plates of Professor Hale and M. Deslandres and our own show the same spectrum of prominence and faculæ, so far as the latter can be observed. The reversals of the H and K lines photographed in prominences are even more easily obtained from the faculæ. The favorable condition of the prominence for the display of its brigt-line spectrum consists in the darker background off the edge of the photosphere, and the same contrast is afforded even more efficiently for the H and K lines of the spectrum of faculæ by the extensive calcium absorption in the solar atmosphere. Father Secchi has put on record a remarkable phenomenon sketched by Tacchini on August 8, 1865; a luminous appendage to the Sun was seen as it was setting below the sea line of the Mediterranean, the appearance was that of a prominence; but its height greatly exceeded anything of the kind witnessed in the spectroscope. The time corresponded exactly to that of the arrival upon the solar limb of an extensive facula sketched at the Observatory of the Roman College on the previous day; and the two drawings are strikingly similar. There can be no doubt about the possibility of this very exceptional phenomenon. It only supposes that the condition of our atmosphere was, at the time, that of an excellent filtering cell for the hydrogen red light, all along the horizontal line of sight towards the setting Sun: a very exceptional condition of things, and only twice utilized so far as we learn from Father Secchi, once by Tacchini on the setting Sun in the Mediterranean, and once at the rising of the Sun at Poestum by an unnamed traveller.*

The third postulate for the acceptance of the proposed genesis of the spot, needs more consideration, in as much as it is not universally accepted as true. This is the precedence of faculæ to spot formation. It is not a necessary consequence of the process traced out; but the complete absence of the priority of faculæ would greatly weaken the claims we are advancing. It is possible that the extra brilliancy of the faculous covering of the spot, at its birth, should be so nearly balanced by the underneath darkening of the photosphere, as to present no apparent change from the normal surface-radiation; the loss of light may even be greater than its increment, when the spot would be the first to show itself; but we should expect that, sometimes at least, the bright radiant mass of uplifted gases should have the advantage, and shine as luminous clouds concealing the under darkness; and examples of this are not wanting. Two of these have been recorded in a note to the *Monthly Notices* R. A. S. for December, 1891,† and reprinted in ASTRONOMY AND ASTRO-PHYSICS for March, 1892; and four others have been added to these in the course of the examination of the Stonyhurst drawings of solar spots and faculæ in the minimum period of 1889. These have been mentioned in the report of the Observatory in the *Monthly Notices* for February, 1893.‡ It will suffice here to formulate the conclusion of our studies of the life histories of the spots of this period—that whereas no clear examples have been found of a

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* Bull. Meteorol. Coll. Rom., 1867, p. 87.

† *Monthly Notices*, R. A. S., Vol. LII, p. 104.

‡ *Monthly Notices*, R. A. S., Vol. LIII, p. 251.

spot appearing before faculæ, we have six undeniable spot births in the midst of small bright patches of faculæ which had formed within the one or two preceding days.

So far the prominent features of a solar spot are reasonably accounted for. There are other facts in the histories of their life-periods which need explanation. The long duration of the dark nucleus and still longer life of the faculæ present no difficulty when the magnitude of the disturbed masses is approximately realized. We are dealing with unknown masses, it is true, but we cannot doubt their greatness in the enormous volumes which they occupy. Months give time short enough for the re-establishment of heat equilibrium in regions so vast as these. But we have yet no clue to the cause of duplicate spots or to the apparent repulsive action between them. In all the greater disturbances there are two dark centres, and these continuously separate from one another until one of them fades away. There is too great uniformity in the pairs to admit the supposition of chance proximity; and their slow separation is too constant to leave any doubt about a physical relationship between the companions. We as naturally look to electricity, as the medical man turns to nerve centres, to account for seemingly unexplainable phenomena. No one will doubt that there must be great electrical disturbances in connection with spot-formation; and the separation of the two nuclei would point to the action of similar electrifications, if we had grounds for admitting an intensity equal to the effect at the immense distances between them. But electrification offers no sort of answer to the question why there should be two centres of disturbance not oppositely electrified.

STONYHURST COLLEGE OBSERVATORY.

ON THE THEORY OF STELLAR SCINTILLATION.*

LORD RAYLEIGH, SEC. R. S.

Arago's theory of this phenomenon is still perhaps the most familiar, although I believe it may be regarded as abandoned by the best authorities. According to it the momentary disappearance of the light of the star is due to accidental interference between the rays which pass the two halves of the pupil of the eye or the object-glass of the telescope. When the relative retardation amounts to an odd multiple of the half wave-length of any

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* From *Philosophical Magazine*, July 1893.

kind of light, such light, it is argued, vanishes from the spectrum of the star. But this theory is based upon a complete misconception. "It is as far as possible from being true that a body emitting homogeneous light would disappear on merely covering half the aperture of vision with a half wave-plate. Such a conclusion would be in the face of the principle of energy, which teaches plainly that the retardation in question would leave the aggregate brightness unaltered."[*] It follows indeed from the principle of interference that there will be darkness at the precise point which before the introduction of the half wave-plate formed the centre of the image, but the light missing there is to be found in a slightly displaced position.[†]

The older view that the scintillation is due to the actual diversion of light from the aperture of vision by atmospheric irregularities was powerfully supported by Montigny,[‡] to whom we owe also a leading feature of the true theory, that is the explanation of the chromatic effects by reference to the different paths pursued by rays of different colors in virtue of *regular* atmospheric dispersion. The path of the violet ray lies higher than that of the red ray which reaches the eye of the observer from the same star, and the separation may be sufficient to allow the one to escape the influence of an atmospheric irregularity which operates upon the other. In Montigny's view the diversion of the light is caused by total reflexion at strata of varying density.

But the most important work upon this subject is undoubtedly that of Respighi[§], who, following in the steps of Montigny and Wolf, applied the spectroscope to the investigation of stellar

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[*] *Enc. Brit.*, "Wave Theory," p 441.

[†] Since the remarks in the text were written I have read the version of Arago s theory given by Mascart (*Traite d'Optique*, t. iii., p. 348). From this some of the most objectionable features have been eliminated. But there can be no doubt as to Arago's meaning. "Supposons que les rayons qui tombent à gauche du centre de l'objectif aient rencontré, depuis les limites supérieures de l'atmosphère, des couches qui, à cause de leur densité, de leur température, ou de leur état hygrométrique, étaient douées d'une réfringence différente de celle que possédaient les couches traversées par les rayons de droite; il pourra arrivér, qu'à raison de cette différence de réfringence, les rayons rouges de droit détruisent *en totalite* les rayons rouges de gauche, et que le foyer passe du blanc, son état normal, au vert; . . . . Voilà donc le résultat théorique parfaitement d'accord avec les observations; violà le phénomène de la scintillation dans une lunette rattaché d'une manière intime à la doctrine des interférences" (*l'Annuaire du Bureau des Longitudes pour* 1852, pp. 423, 425).

That the difference between Arago's theory and that followed in the present paper is fundamental will be recognized when it is noticed that, according to the former, the color effects of scintillation would be nearly independent of atmospheric *dispersion*. Arago gives an interesting summary of the views held by early writers.

[‡] *Mem. de l'Acad. de Bruxelles*, t. xxviii. (1856).

[§] *Roma, Atti Nuovi Lincei*, xxi (1868); *Assoc. Francaise, Compt. Rend.* i (1872) p. 169.

scintillation. The results of these observations are summed up under thirteen heads, which it will be convenient to give almost at full length.

(I.) In spectra of stars near the horizon we may observe dark or bright bands, transversal or perpendicular to the length of the spectrum, which more or less quickly travel from the red to the violet, or from the violet to the red, or oscillate from one to the other color; and this however the spectrum may be directed from the horizontal to the vertical.

(II.) In normal atmospheric conditions the motion of the bands proceeds regularly from red to violet for stars in the west, and from violet to red for stars in the east; while in the neighborhood of the meridian the movement is usually oscillatory, or even limited to one part of the spectrum.

(III.) In observing the horizontal spectra of stars more and more elevated above the horizon, the bands are seen sensibly parallel to one another, but more or less inclined to the axis of the spectrum, passing from red to violet or reversely according as the star is in the west or the east.

(IV). The inclination of the bands, or the angle formed by them with the axis (? transversal) of the spectrum depends upon the height of the star; it reduces to 0° at the horizon and increases rapidly with the altitude so as to reach 90° at an elevation of 30° or 40°, so that at this elevation the bands become longitudinal.

(V.) The inclination of the bands, reckoned downwards, is towards the more refrangible end of the spectrum.

(VI.) The bands are most marked and distinct when the altitude of the star is *least*. At an altitude of more than 40° the longitudinal bands are reduced to mere shaded streaks, and often can only be observed upon the spectrum as slight general variations of brightness.

(VII.) As the altitude increases, the movement of the bands becomes quicker and less regular.

(VIII.) As the prism is turned so as to bring the spectrum from the horizontal to the vertical position, the inclination of the bands to the transversal of the spectrum continually diminishes until it becomes zero when the spectrum is nearly vertical; but the bands then become less marked, retaining, however, the movement in the direction indicated above (III).

(IX.) Luminous bands are less frequent and less regular than dark bands, and occur well marked only in spectra of stars near the horizon.

(X.) In the midst of this general and violent movement of bright and dark masses in the spectra of stars, the black spectral lines proper to the light of each star remain sensibly quiescent or undergo very slight oscillations.

(XI.) Under abnormal atmospheric conditions the bands are fainter and less regular in shape and movement.

(XII.) When strong winds prevail the bands are usually rather faint and ill defined, and then the spectrum exhibits mere changes of brightness, even in the case of stars near the horizon.

(XIII.) Good definition and regular movement of the bands seems to be a sign of the probable continuance of fine weather, and, on the other hand, irregularity in these phenomena indicates probable change.

These results show plainly that the changes of intensity and color in the images of stars are produced by a momentary real diversion of the luminous rays from the object-glass of the telescope; that in the neighborhood of the horizon rays of different colors are affected separately and successively, and that all the rays of a given color are momentarily withdrawn from the whole of the object-glass.

Most of his conclusions from observation were readily explained by Respighi as due to irregular refractions, not necessarily or usually amounting (as Montigny supposed) to total reflections, taking place at a sufficient distance from the observer. The progress of the bands in one direction along the spectrum (II.) is attributed to the diurnal motion. In the case of a setting star, for instance, the blue rays by which it is seen, pursuing a higher course through the atmosphere, encounter an obstacle somewhat later than do the red rays. Hence the band travels toward the violet end of the spectrum. In the neighborhood of the meridian this cause of a progressive movement ceases to operate.

The observations recorded in (III.) are of special interest as establishing a connection between the rates with which various parts of the object-glass and of the spectrum are affected. Since the spectrum is horizontal, various parts of its width correspond to various horizontal sections of the objective, and the existence of bands at a definite inclination shows that at the moment when the shadow of the obstacle thrown by blue rays reaches the bottom of the glass the shadow at the top is that thrown by green, yellow or red rays of less refrangibility. When the altitude of the star reaches 30° or 40°, the difference of path due to atmospheric dispersion is insufficient to differentiate the various parts of the spectrum. The bands then appear longitudinal.

The *definite* obliquity of the bands at moderate altitudes, reported by Respighi, leads to a conclusion of some interest, which does not appear to have been noticed. In the case of a given star, observed at a given altitude, the linear separation at the telescope of the shadows of the same obstacle thrown by rays of various colors will of necessity depend upon the distance of the obstacle. But the definiteness of the obliquity of the bands requires that this separation shall not vary, and therefore that the obstacles to which the effects are due are sensibly at one distance only. It would seem to follow from this that, under "normal atmospheric conditions," scintillation depends upon irregularities limited to a comparatively narrow horizontal stratum situated overhead. A further consequence will be that the distance of the obstacles increases as the altitude of the star diminishes, and this according to a definite law.

The principal object of the present communication is to exhibit some of the consequences of the theory of scintillation in a definite mathematical form. The investigation may be conducted by simple methods, if, as suffices for most purposes, we regard the whole refraction as small, and neglect the influence of the Earth's curvature. When the object is to calculate with accuracy the refraction itself further approximations are necessary, but even in this case the required result can be obtained with more ease than is generally supposed.

The foundation upon which it is most convenient to build is the idea of James Thomson,* which establishes instantaneously the connection between the curvature of a ray travelling in a medium of varying optical constitution and the rate at which the index changes at the point in question. The following is from Everett's memoir:

"Draw normal planes to a ray at two consecutive points of its path. Then the distance of their intersection from either point will be ρ, the radius of curvature. But these normal planes are tangential to the wave-front in its two consecutive positions. Hence it is easily shown by similar triangles that a very short line dN drawn from either of the points towards the centre of curvature is to the whole length ρ, of which it forms part, as dv the difference of the velocities of light at its two ends is to v the velocity at either end. That is,

$$dN/\rho = -dv/v,$$

the negative sign being used because the velocity diminishes in ap-

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* Brit. Assoc. Rep. 1872. Everett *Phil. Mag.* March 1873.

proaching the centre of curvature. But since v varies inversely as μ, we have

$$-dv/v = d\mu/\mu.$$

Hence the curvature $1/\rho$ is given by any of the four following expressions:

$$\frac{1}{\rho} = -\frac{1}{v}\frac{dv}{dN} = -\frac{d\log v}{dN} = \frac{1}{\mu}\frac{d\mu}{dN} = \frac{d\log\mu}{dN} \qquad (1)$$

"The curvatures of different rays at the same point are directly as the rates of increase of μ in travelling along their respective normals." If θ denote the angle which the ray makes with the direction of most rapid increase of index, the curvatures will be directly as the values of $\sin\theta$. In fact, if $d\mu/dr$ denote the rate at which μ increases in a direction normal to the surfaces of equal index, we have

$$\frac{d\mu}{dN} = \frac{d\mu}{dr}\sin\theta,$$

and therefore

$$\pm\frac{1}{\rho} = \frac{1}{\mu}\frac{d\mu}{dr}\sin\theta = \frac{d\log\mu}{dr}\sin\theta. \qquad (2)$$

Everett shows how the well-known equation

$$\mu p = \text{const.} \qquad (3)$$

can be deduced from (2), p being the perpendicular upon the ray from the centre of *spherical* surfaces of equal index. In general,

$$\frac{1}{\rho} = \frac{1}{r}\frac{dp}{dr}, \quad \sin\theta = \frac{p}{r},$$

and thus

$$-\frac{1}{r}\frac{dp}{dr} = \frac{p}{r}\frac{d\log\mu}{dr},$$

giving (3) on integration.

At a first application of (2) we may find by means of it a first approximation to the law of atmospheric refraction, on the supposition that the whole refraction is small and that the curvature of the Earth may be neglected. Under these limitations θ in (2) may be treated as constant along the whole path of the ray; and if $d\psi$ be the angle through which the ray turns in describing the element of arc ds, we have

$$d\psi = \frac{d\log\mu}{dr}\sin\theta ds = \tan\theta\, d\log\mu.$$

If we integrate this along the whole course of the ray through the atmosphere, that is from $\mu = 1$ to $\mu = \mu_0$, we get, as the whole refraction,

$$\psi = \log \mu_0 \tan \theta = (\mu_0 - 1) \tan \theta, \tag{4}$$

for to the order of approximation in question $\log \mu_0$ may be identified with $(\mu_0 - 1)$.

If $\delta\psi$ denote the chromatic variation of ψ corresponding to $\delta\mu_0$, we have from (4)

$$\delta\psi/\psi = \delta\mu_0/(\mu_0 - 1). \tag{5}$$

According to Mascart* the value of the right-hand member of (5) in the case of air and of the lines B and H is

$$\delta\mu_0/(\mu_0 - 1) = .024. \tag{6}$$

We will now take a step further and calculate the linear deviation of a ray from a straight course, still upon the supposition that the whole refraction is small. If η denote the linear deviation (reckoned perpendicularly) at any point defined by the length s measured along the ray θ, we have

$$\frac{d^2\eta}{ds^2} = \frac{1}{\rho} = \tan \theta \frac{d \log \mu}{ds},$$

so that

$$\frac{d\eta}{ds} = \int \tan \theta \, d \log \mu = \tan \theta (\mu - 1) + \alpha,$$

α being a constant of integration. A second integration now gives

$$\eta = \tan \theta \int (\mu - 1) ds + \alpha s + \beta \tag{7}$$

which determines the path of the ray. If y be the height of any point above the surface of the Earth, $ds = dy \sec \theta$; so that (7) may also be written

$$\eta = \frac{\sin \theta}{\cos^2 \theta} \int (\mu - 1) dy + \alpha s + \beta \tag{8}$$

The origin of s is arbitrary, but we may conveniently take it at the point (A) where the ray strikes the Earth's surface.

We will now consider also a second ray, of another color, deviating from the line θ by the distance $\eta + \delta\eta$ and corresponding to a change of μ to $\mu + \delta\mu$. The distance between the two rays at any point y is

$$\delta\eta = \frac{\sin \theta}{\cos^2 \theta} \int_0^y \delta\mu dy + d\alpha \, . \, s + \delta\beta \tag{9}$$

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* Everett's C.G.S. System of Units.

In this equation $\delta\beta$ denotes the separation of the rays at A, where $y = 0$, $s = 0$. And $\delta\alpha$ denotes the angle between the rays when outside the atmosphere.

Equation (9) may be applied at once to Montigny's problem, that is to determine the separation of two rays of different colors, both coming from the same star, and both arriving at the same point A. The first condition gives $\delta\alpha = 0$, and the second gives $\delta\beta = 0$. Accordingly,

$$\delta\eta = \frac{\sin\theta}{\cos^2\theta}\int_0^y \delta\mu dy \qquad (10)$$

is the solution of the question.

The integral in (10) may be otherwise expressed by means of the principle that $(\mu - 1)$ and $\delta\mu$ are proportional to the density. Thus, if l denote the "height of the homogeneous atmosphere," and h the elevation in such an atmosphere determined by the condition that there shall be as much air below it as actually exists below y,

$$\int_0^y \delta\mu dy = \delta\mu_0 h \qquad (11)$$

$\delta\mu_0$ being the value of $\delta\mu$ at the surface of the Earth. Equation (10) thus becomes

$$\delta\eta = \frac{\delta\mu_0 h \sin\theta}{\cos^2\theta} \qquad (12)$$

At the limits of the atmosphere and beyond, $h = l$, and the separation there is

$$\delta\eta = \frac{\delta\mu_0 l \sin\theta}{\cos^2\theta} \qquad (13)$$

These results are applicable to all altitudes higher than about 10°.

The formulæ given by Montigny (*loc. cit.*) are quite different from the above. That corresponding to (13) is

$$\delta\eta = \delta\mu_0\, a \sin\theta, \qquad (14)$$

a being the radius of the Earth! The substitution of a for l increases the calculated result some 800 times. But this is in a large measure compensated by the factor $\sec^2\theta$ in (13), for at low altitudes $\sec\theta$ is large. According to Montigny the separation at moderately low altitudes would be nearly independent of the altitude, a conclusion entirely wide of the truth.

The value of $(\mu_0 - 1)$ for air at 0° and 760 millim. at Paris is .0002927, so that $\delta\mu_0$ (for the lines B and H) is .000007025. The height of the homogeneous atmosphere is 7.990 × 10^5 centim., and thus $\delta\eta$ reckoned in centim. is

$$\delta\eta = 5.612\,\frac{h\sin\theta}{l\cos^2\theta}. \tag{15}$$

The following are a few corresponding values of θ and $\sin\theta/\cos^2\theta$:

θ	$\sin\theta/\cos^2\theta$	θ	$\sin\theta/\cos^2\theta$
0°	0.000	60°	3.46
20	0.387	70	8.03
40	1.095	80	32.66

Thus at the limit of the atmosphere the separation of rays which reach the observer at an apparent altitude of 10° is 185 centim. Nearer the horizon the separation would be still greater, but its value cannot well be found from (15). Although these estimates are considerably less than those of Montigny, the separation near the horizon seems to be sufficient to explain the vertical position of the bands in the spectrum, recorded by Respighi (I). The fact that the margin is not very great suggests that the obstacles to which scintillation is due may often be situated at a considerable elevation.

We have now to consider the effect of an obstacle situated at a given point B at level y on the course of the ray. And the first desideratum will be the estimation of the separation at A, the object-glass of the telescope, of rays of various colors coming from the same star, which all pass through the given point B. It will appear at once that no fresh question is raised. For since the rays come from the same star at the same time, $\delta\alpha = 0$, and thus by (9) $\delta\eta_A = \delta\beta$. The value of $\delta\beta$ is given at once by the condition that $\delta\eta_B = 0$. Thus.

$$-\,\delta\eta_A = \frac{\sin\theta}{\cos^2\theta}\int_0^y \delta\mu\,dy = \frac{\delta\mu_0\,h\sin\theta}{\cos^2\theta}, \tag{16}$$

as before. The discussion, already given of (15), is thus immediately applicable.

Equation (16) solves the problem of determining the inclination of the bands seen in the spectra of stars not very low (III). It is only necessary to equate $-\,\delta\eta_A$ to the aperture of the telescope. $\delta\mu_0$ then gives the range of refrangibility covered by the bands as inclined. In practice h would not be known beforehand; but from the observed inclination of the bands it would be possible to determine it.

In a given state of the atmosphere h, so far as it is definite, must be constant and then $\delta\mu_0$ must be proportional to $\cos^2\theta/\sin\theta$.

This gives the relation between the altitude of the star and the inclination of the bands.

When θ is small, $\delta\mu_0$ is large; that is the bands become longitudinal.

As a numerical example, let us suppose that the aperture of the telescope is 10 centim., and that at an altitude of 10° the obliquity of the bands is such that the vertical diameter of the object-glass corresponds to the entire range from B to H. In this case (15) gives

$$h = \frac{10\,l}{185} = .054\ l,$$

indicating that the obstacles to which the bands are due are situated at such a level that about $\frac{1}{20}$ of the whole mass of the atmosphere is below them.

The next question to which (9) may be applied is to find the angle $\delta\alpha$ outside the atmosphere between two rays of different colors which pass through the *two* points A and B. Here $\delta\eta_A = 0$, and thus $\delta\beta = 0$. And further, since $\delta\eta_B = 0$, we get

$$-\,\delta\alpha = \frac{\sin\theta}{s\cos^2\theta}\int_0^y \delta\mu\,dy = \frac{\delta\mu_0 h\tan\theta}{y} \qquad (17)$$

If the height of the obstacle above the ground be so small that the density of the air below it is sensibly uniform, then $h = y$, and

$$-\,\delta\alpha = \delta\mu_0 \tan\theta. \qquad (18)$$

In this case the angle is the same as that of the spectrum of the star observed at A, as appears from (4) and (5). In general, y is greater than h, so that $\delta\alpha$ is somewhat less than the value given by (18).

The interest of (18) lies in the application of it to find the time occupied by a band in traversing the spectrum in virtue of the diurnal motion, according to Respighi's observation (II). The time required is that necessary for the star to rise or fall through the angle of its dispersion-spectrum at the altitude in question. At an altitude of 10°, this angle will be 8″, being always about $\frac{1}{40}$ of the whole refraction. The rate at which a star rises or falls depends of course upon the declination of the star and upon the latitude of the observer, and may vary from zero to 15° per hour. At the latter maximum rate the star would describe 8″ in about one half of a second, which would therefore be the time occupied by a band in crossing the spectrum under the circumstances supposed. In the case of a star quite close to the horizon, the progress of the band would be a good deal slower.

The fact that the larger planets scintillate but little, even under favorable conditions, is readily explained by their sensible apparent magnitude. The separation of rays of one color thus arising during their passage through the atmosphere is usually far greater than the already calculated separation due to chromatic dispersion; so that if a fixed star of no apparent magnitude scintillates in colors, the different parts of the area of a planet must *à fortiori* scintillate independently. But under these circumstances the eye perceives only an average effect, and there is no scintillation visible.

The non-scintillation of small stars situated near the horizon may be referred to the failure of the eye to appreciate color when the light is faint.

In the case of stars higher up the whole spectrum is affected simultaneously. A momentary accession of illumination, due to the passage of an atmospheric irregularity, may thus render visible a star which on account of its faintness could not be steadily seen through an undisturbed atmosphere.*

In the preceding discussion the refracting obstacles have for the sake of brevity been spoken of as throwing sharp shadows. This of course cannot happen, if only in consequence of diffraction; and it is of some interest to inquire into the magnitude of the necessary diffusion. The theory of diffraction shows that even in the case of an opaque screen with a definite straight boundary, the transition of illumination at the edge of the shadow occupies a space such as $\sqrt{(b\lambda)}$, where λ is the wavelength of the light, and b is the distance across which the shadow is thrown. We may take λ at 6×10^{-5} centim., and if b be reckoned in kilometers, we have as the space of transition, $\sqrt{(6b)}$. Thus if b were 4 kilometers, the space of transition would amount to about 5 centim. The inference is that the various parts of the aperture of a small telescope cannot be very differently affected unless the obstacles to which the scintillation is due are at a less distance than 4 kilometres.

One of the principal outstanding difficulties in the theory of scintillation is to see how the transition from one index to another in an atmospheric irregularity can be sufficiently sudden. The fact that the various parts of a not too small object-glass are diversely affected seems to prove that the transitions in question do not occupy many centimetres. Now whether the irregularity be due to temperature or to moisture, we should expect

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* The theory of Arago leads him to a directly opposite conclusion (*loc. cit.* p. 381).

that a transition, however abrupt at first, would after a few minutes or hours be eased off to a greater degree than would accord with the above estimate. Perhaps the abruptness of transition is, as it were, continually renewed by the coming into contact of fresh portions of light and dense air as the ascending and descending streams proceed in their courses. The speculations and experiments of Jevons on the Cirrus form of cloud* may find some application here. A preliminary question requiring attention is as to the origin of the irregularities which cause scintillation. Is it always at the ground, and mainly under the influence of sunshine? Or may irregular absorption of solar heat in the atmosphere, due to varying proportions of moisture, give rise to transitions of the necessary abruptness? Again, we may ask how many obstacles are to be supposed operative upon the same ray? Is the ultimate effect only a small residue from many causes in the main neutralizing one another? It does not appear that in the present state of meteorological science satisfactory answers can be given to these questions.

[TO BE CONTINUED.]

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

M. Janssen's Spectroscopic Observations on Mont Blanc.—In the *Comptes Rendus* of Sept. 25, M. Janssen describes his recent ascent of Mont Blanc, where a small observatory has been so nearly completed as to permit of its occupancy. In continuation of his well-known investigations on the absorption spectrum of oxygen he observed the B group in the solar spectrum with a much more powerful spectroscope than that used in his earlier work. This instrument has a Rowland grating and telescopes of 75 cm. focal length, and gives the B group in all its details. The employment of this instrument is a matter of some importance, as the spectroscope formerly used was not capable of resolving the group. The doublets which constitute the B group decrease in intensity as their wave-length increases, and the fainter doublets disappear successively as the absorptive action of the atmosphere diminishes. At the sea-level there are (according to M. Janssen) 13 or 14 doublets in addition to the "head" of the group. At Chamonix (1050 metres) the thirteenth doublet is seen with difficulty. At the Grands-Mulets (3050 metres) only 11 or 12 doublets are visible, while on the summit of Mont Blanc the number is reduced to 8.

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* Phil. Mag. xiv. p. 22, 1857. For a mathematical investigation, by the author, see Math. Soc. Proc. xiv, April, 1883.

M. Janssen finds that if the co-efficient which represents the diminution of atmospheric pressure at the summit of Mont Blanc

$$\left(\frac{0.43}{0.76}=0.566\right)$$

is multiplied by the number 13 representing the doublets ordinarily clearly visible at the sea-level, the result is 7.4, or very nearly the number (8) of doublets visible at the summit of the mountain. But M. Janssen regards the law of diminution of doublets as in reality much more complex, and he has undertaken to reproduce at Meudon the phenomena observed at various altitudes, by means of tubes filled with oxygen, which can be subjected to any desired pressure. Preliminary experiments have led to the conclusion that the groups A, B and α would disappear from the solar spectrum at the limit of the atmosphere. In order to test whether the absorptive power of oxygen may not be of a peculiar character in the Sun on account of its high temperature M. Janssen has observed the absorptive spectra of the gas at temperatures of from 400° to 500°, but without detecting any appreciable modification.

A New Edition of Miss Clerke's History of Astronom
years since the publication of the Second Edition of t
marvellously fruitful of astronomical discoveries. H
was called for, and has been executed without stint of
and substitutions have been freely made; and it has b
not only to furnish a large amount of requisite new inf
ate it so completely with the pre-existing text as to lea
tive suggesting "interpolations" to the refined critic
from the Preface to the Third Edition of Miss Agnes
History of Astronomy during the Nineteenth Century, i
new edition, and Miss Clerke's former readers will not b
this purpose has been most admirably fulfilled. The bo
yet it deals with the present century's contributions to
tional way. That it has been thoroughly brought
evidenced by the fact that the two eclipses of 1889, the
fessors Bigelow and Schaeberle, the most recent spectro
investigations of the Sun, the variation of latitude, the
and the remarkable history of Nova Aurigæ, have been
The addition of five excellent photogravure plates,
of the Solar Chromosphere and Prominences, the Gre
1882, Swift's Comet, the Spectrum of Nova Aurigæ
Sagittarius much increases the value of the work over fo
To every student of astronomy, and especially to the
ber whose chief interest is in the progress of astro-ph
heartily recommend this book.

On the Absorption Spectra of Copper Salts.—The
aqueous solutions of copper chloride, sulphate and nitr
by Ewan, using Krüss's universal spectrometer for the
Vierordt's method. The conclusions reached in the invest
up as follows: (1). On diluting their solutions the abso
three salts examined are observed to change; (2) the ch

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* Macmillan & Co., New York.

is such as to show that the spectra in dilute solutions tend to become identical; (3) the behavior of the salts examined leads to the conclusion that in strong solutions the acid and basic parts of the salts are associated in producing absorption of light, whilst in dilute solutions they act independently in doing so; (4) these results are substantially in agreement with the hypothesis of electrolytic dissociation; (5) and finally the results obtained do not seem to be satisfactorily explicable upon the hypothesis of a hydrolytic dissociation or on that of molecular aggregates.—(*Am. Jour. Sci.*, October, 1893.)

Polarization of Undiffracted Ultra Red Radiations by Wire Gratings.—Du Bois and Rubens. (*Wied. Ann.*, Bd. 49, p. 593, 1893.)—Some recent experiments by duBois show that polarized light passing directly (without diffraction) through a wire grating has its plane of polarization rotated. By the rotation the plane larization is made more nearly perpendicular to the direction of the wires of rating; and this effect was explained by assuming that the grating was transparent to light polarized perpendicular to the wires than to that lel to them.

ince Troughton has shown* that the electrical vibration in polarized light be considered as perpendicular to the plane of polarization, this result is ary to the fact found by Hertz, viz., that a wire grating is transparent to ical vibrations perpendicular to the direction of the wires but perfectly ue to those parallel to the wires.

his want of agreement led to the further researches by du Bois and Rubens, considered, on the relative transparency of fine wire gratings for light ized parallel and perpendicular to the wires. To approach as near as possi- Hertz conditions the gratings were as fine as possible and the wave-lengths eat as could be used. Wires for the purpose were drawn of Pt, Cu, Fe, Au Ag of diameters ranging from .0025 cm. to .006 cm. Two of these of the diameter were wound on a frame and one then unwound, leaving a grating ich the transparent and opaque portions were equal. The light of a Zircon- urner or arc light was polarized by reflection from a pile of glass plates, hrough the grating, and its intensity measured by a spectrophotometer cross hair was represented by the wire of a bolometer. The grating was unted that it could be readily rotated 90° about an axis parallel to the ion of the light and thus its relative transparency in the two positions meas- or the particular wave-length for which the bolometer wire was adjusted.

we call n^2 the ratio of transparency for light polarized perpendicular to olarized parallel to the grating wires, and draw a curve with the values of ordinates and the corresponding wave-lengths for abscissæ, this curve will a maximum in the ultra red and for still greater wave-lengths will cross e $n^2 = 1$. For wave-lengths beyond this point the grating is more trans- for light polarized parallel to the wires; agreeing in this region with the of Hertz.

e values of the wave-lengths for which n^2 is a maximum and for which it y depend on the material of the grating but not upon the size of the wires the spaces. For the longest wave-lengths n^2 approaches the same value for gratings and for the oscillations used by Hertz there would doubtless be ference between copper and iron wires.

e results of the previous experiments of du Bois and of Hertz are thus

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* *Phil. Mag.*, Vol. 32, p. 80, (1891).

linked together and the present researches must be considered as affording a new and important confirmation to the identity of light waves and the electrical oscillations of Hertz.

In explanation of the facts it is suggested that there are probably two actions, one tending to weaken the vibrations perpendicular to the wires, the other weakening those at right angles to this. So long as the wave-length is very small compared with the size of the wires. the former effect exceeds the latter while for greater wave-lengths the reverse is true. For the short wave-lengths it is likely that the action is closely associated with the "Gouy-wien" phenomenon. For greater values of the wave-length it would appear (as in Hertz' experiments) that the freedom of electrical motion in the direction of the wires produces a greater opacity to vibrations in this direction.

The experimenters have also investigated the accuracy of the formula used by Sirks for the effect of wire screens on the brilliance of the image of a star. For the fine gratings used here a departure from the law was found, but assuming a law of deviation pointed out by Lorentz and Sande-Bakhuyzen, the error in the gratings used by Sirks amounts to but 0.03 magnitudes in the determination of the brilliance of the star. C. A. PERKINS.

Erratum in No. 118, October, 1893.

WASHINGTON, D. C., Oct. 10, 1893.

THE EDITOR OF ASTRONOMY AND ASTRO-PHYSICS:

In the foot note to the table of "deflecting forces" in article on "The Two Magnetic Fields surrounding the Sun," make it read, s_1 *units of 5th decimal,* instead of s_1 units of 6th decimal, to conform to the statement in the text, page 710, line 10. Very respectfully,

FRANK H. BIGELOW.

Astronomical Journal Prizes.—By the last *Astronomical Journal* (305) it is stated that the judges for the award of the *Journal* prizes suggest that the period specified in the offer of the prize for the observations of comets found on page 160 of No. 1, Vol. XII, be extended by six months, to Sept. 30, 1894, for the following reasons:

"During the past six months but one comet has been discovered, and the period of its visibility was unusually short. Meanwhile winter is approaching during which the usually prevailing climatic conditions are likely to reduce chances for observation, even if the supply of new comets should not be restricted, as is usual, for the same reason. It is therefore probable, that from causes beyond the control of the observers, there will be adequate opportunity for worthy competition for so generous a prize.

To meet this unforeseen state of things by a measure in the interests of the candidates for the award, and fair to all of them alike, the above extension of time is proposed. The judges courteously recommend that, if the suggestion meets the approval of the donor, the terms of the offer should be modified in accordance therewith.

The donor of the prizes has assented to the change of conditions above named.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR DECEMBER.

Mercury will be morning planet during December and will be visible to the unaided eye during the middle of the month. One must look toward the southeast about an hour before sunrise in order to see it. Mercury will be at greatest elongation, west from the Sun 21° 23′, Dec. 14 at noon.

Venus will be evening planet during December setting in the southwest between seven and eight P. M. Although so brilliant to the eye it will not, on account of its low altitude, be in good position for telescopic observation in northern latitudes. Venus will be at greatest elongation, east from the Sun 47° 29′, Dec. 6 at 3^h 36^m P. M. In the southern hemisphere this will be a very favorable opportunity to study the surface markings of Venus and it is to be hoped that Professor W. H. Pickering and his assistants at Arequipa will be able to add much to our knowledge of this subject and of the rotation of the planet.

Mars will be morning planet, but is getting farther south all the time so that its position will be unfavorable for northern observers. In the southern hemisphere the conditions will be much better. There will be quite a close conjunction of *Mars* and *Uranus* Dec. 6 at 4^h 09^m central time, when the former will be only 8′ north of the latter. Observers in Australia and Japan should be able to see the two planets in the same field of view of the telescope. The ruddy color of Mars and the green hue of Uranus will present a striking contrast. Eighteen hours later Mars will pass close to the wide double star α Libræ, the components of which Webb puts as third magnitude, pale yellow, and sixth magnitude light grey. Mars will pass 11′ north of the brighter star.

Jupiter, having but just passed opposition, will be in excellent position for observation during December. We have had a few good views of the planet this year when much of fine detail was seen upon the surface, notably a large number of very small dark red spots. We have not happened to look at the time when the "great red spot" was visible and cannot say what its appearance this year is. The apparent diameter of Jupiter during December diminishes from 46″ to 44″. His brilliancy will be greater than that of any other object in the evening sky, excepting the Moon, so that none can mistake him. His course is slowly westward in Taurus.

Saturn will be visible in the morning, but at a low altitude, so that for northern observers there will be no satisfactory observations. Saturn is in the constellation Virgo just a little north and east of the star Spica. The planet is the brighter of the two. The rings of Saturn are pretty well opened now, the angle of their plane to the line of sight being now about 12°, and increasing to 14° at the end of December. Saturn and the Moon will be in conjunction Dec. 3 at 3^h 20^m P. M. and Dec. 31 at 1^h 41^m A. M. Saturn will be about 3° north of the Moon in both instances.

Uranus is in Libra very close to the star α, referred to above in the note on Mars. At 5^h 32^m on the morning of Dec. 16, Uranus will be in conjunction with the star, only 3′ north. The conjunction with Mars has already been mentioned.

Neptune will be at opposition Dec. 3 and therefore in best position for observation during December. Its motion during the month will be 53′ west and 6′ south. The position Dec. 1 will be one third of the distance on a straight line from ι to ϵ Tauri. A photograph taken at Goodsell Observatory, Oct. 18, shows no star as bright as Neptune within 1° of this position.

PLANET TABLES FOR DECEMBER.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

Date.	R. A.	Decl.	Rises.	Transits.	Sets.
1893.	h m	° ′	h m	h m	h m
			MERCURY.		
Dec. 5	15 40.2	− 16 47	5 47 A. M.	10 41.3 A. M.	3 36 P. M.
15	16 04.5	− 18 38	5 40 "	10 26.3 "	3 13 "
25	16 56.8	− 21 50	6 08 "	10 39.1 "	3 10 "
			VENUS		
Dec. 5	20 16.5	− 22 24	10 48 A. M.	3 17.0 P. M.	7 46 P. M.
15	20 56.8	− 19 20	10 35 "	3 17.7 "	8 01 "
25	21 31.5	− 15 47	10 14 "	3 13.0 "	8 12 "
			MARS.		
Dec. 5	14 39.7	− 15 00	4 38 A. M.	9 41.0 A. M.	2 44 P. M.
15	15 06.1	− 17 01	4 34 "	9 28.2 "	2 22 "
25	15 33.4	− 18 50	4 31 "	9 16.1 "	2 01 "
			JUPITER.		
Dec. 5	3 27.8	+ 17 46	3 10 P. M.	10 27.0 P. M.	5 44 A. M.
15	3 23 4	+ 17 32	2 27 "	9 43.3 "	4 59 "
25	3 19.9	+ 17 22	1 45 "	9 00.6 "	4 16 "
			SATURN.		
Dec. 5	13 25.9	− 6 30	2 50 A. M.	8 27.4 A. M.	2 05 P. M.
15	13 29.1	− 6 47	2 15 "	7 51.4 "	1 28 "
25	13 31.8	− 7 11	1 39 "	7 14.8 "	12 50 "
			URANUS.		
Dec. 5	14 42.7	− 15 22	4 43 A. M.	9 44.1 A. M.	2 45 P. M.
15	14 44.8	− 15 32	4 07 "	9 06.8 "	2 07 "
25	14 46.7	− 15 40	3 30 "	8 29.5 "	1 29 "
			NEPTUNE.		
Dec. 5	4 43.2	+ 20 42	4 11 P. M.	11 42.2 P. M.	7 13 A. M.
15	4 42.0	+ 20 40	3 31 "	11 01.7 "	6 32 "
25	4 40.9	+ 20 38	2 51 "	10 21.3 "	5 52 "
			THE SUN.		
Dec. 5	16 50.1	− 22 29	7 23 A. M.	11 51.0 A. M.	4 19 P. M.
15	17 34.1	− 23 19	7 32 "	11 55.6 "	4 20 "
25	18 18.5	− 23 23	7 37 "	12 00.6 "	4 24 "

Configuration of Jupiter's Satellites at 9:30 p. m. Central Time, for an Inverting Telescope.

Dec.		Dec.		Dec.	
1	2 3 ○ 1 4	12	3 2 ○ 1 4	23	4 1 ○ 2 3
2	1 4 ○ 2 3	13	3 1 ○ 2 4	24	4 ○ 1 2 3
3	4 ○ 2 1 3	14	3 2 1 ○ 4	25	4 2 1 ○ 3
4	4 2 1 ○ 3	15	2 3 ○ 1 4	26	4 2 ○ 3 1
5	4 3 ○ 1 ●	16	1 ○ 2 3 4	27	3 1 ○ 4 2
6	4 3 ○ 2 ●	17	○ 2 1 4 3	28	♃ 3 ○ 1 4
7	4 3 2 1 ○	18	2 1 ○ 4 3	29	3 2 ○ 4 ●
8	4 2 3 ○ 1	19	4 2 ○ 1 ♃	30	1 ○ 2 3 4
9	4 1 ○ 2 3	20	4 3 1 ○ 2	31	○ 1 2 3 4
10	● ○ 2 1 3	21	4 3 ○ ♃ ♃		
11	2 1 ○ 3 4	22	4 2 3 ○ 1		

Elongations of the Satellites of Saturn.

(The western elongations will be found approximately half way between the eastern, and other positions may be easily interpolated.)

MIMAS

		h		
Dec.	9	4.9	A. M.	E
	10	3.5	"	E
	11	2.1	"	E
	12	12.7	"	E
	12	11.3	P. M.	E
	13	9 9	"	E
	14	8.6	"	E
	15	7.3	"	E
	16	5.9	"	E
	17	4.5	"	E
	18	3.1	"	E
	19	1.7	"	E
	20	12.3	"	E
	21	10.9	A. M.	E
	22	9.5	"	E
	23	8.1	"	E
	24	6.8	"	E
	25	5.5	"	E
	26	4.1	"	E
	27	2.7	"	E
	28	1.3	"	E
	28	11.9	P. M.	E
	29	10.5	"	E
	30	9.1	"	E
	31	7.8	"	E

ENCELADUS

		h		
Dec.	15	6.6	A. M.	E
	16	3.5	P. M.	E
Dec.	18	12.4	A. M.	E
	19	9.3	"	E
	20	6.2	P. M.	E
	22	3.1	A. M.	E
	23	11.9	"	E
	24	8.8	P. M.	E
	26	5.7	A. M.	E
	27	2.6	P. M.	E
	28	11.5	"	E
	30	8.4	A. M.	E
	31	5.3	P. M.	E

TETHYS

Dec.	13	5.3	A. M.	E
	15	2.6	"	E
	16	11.9	P. M.	E
	18	9.3	"	E
	20	6.6	"	E
	22	3.9	"	E
	24	1.2	"	E
	26	10.5	A. M.	E
	28	7.8	"	E
	30	5.1	"	E

DIONE

		h		
Dec.	14	8.8	A. M.	E
	17	2.5	"	E
Dec.	19	8.2	P. M.	E
	22	1.9	"	E
	25	7.6	A. M.	E
	28	1.3	"	E
	30	7.0	P. M.	E

RHEA

Dec.	6	1.8	P. M.	E
	11	2.4	A. M.	E
	15	2.9	P. M.	E
	20	3.4	A. M.	E
	24	3.9	P. M.	E
	29	4.4	A. M.	E

TITAN

Dec.	14	6.9	P. M.	W
	22	4.3	"	E
	30	6.1	"	W

HYPERION

Dec.	15	8.4	P. M.	E
	27	2.2	"	W

JAPETUS

Dec.	10	6.2	A. M.	W
	30	4.5	P. M.	S

Occultations Visible at Washington.

Date 1893.		Star's Name.	Magnitude.	IMMERSION Washington M. T.		IMMERSION Angle f'm N pt.	EMERSION Washington M. T.		EMERSION Angle f'm N pt.	Duration.	
				h	m	°	h	m	°	h	m
Dec.	10	B.A.C. 6628	5.9	5	21	110	6	25	211	1	04
	17	ζ Piscium	4.8	13	18	99	14	04	213	0	56
	19	40 Arietis	6.3	6	32	359	7	08	294	0	36
	20	36 Tauri	6.0	14	12	97	15	11	245	0	59
	23	47 Geminorum	6.0	5	43	102	6	31	254	0	48
	24	λ Cancri	5.7	6	43	106	7	33	266	0	50
	30	86 Virginis	5.9	16	57	89	17	59	351	1	02

Phases and Aspects of the Moon.

		Central Time. d	h m	
New Moon	Dec.	8	1 40	A. M.
Apogee	"	9	5 24	A. M.
First Quarter	"	16	4 21	A. M.
Perigee	"	22	9 18	P. M.
Full Moon	"	22	10 37	P. M.
Last Quarter	"	29	5 18	P. M.

Phenomena of Jupiter's Satellites.

		h	m			
Dec.	2	1	48	A. M.	III	Oc. Dis.
		4	46	"	III	Ec. Re.
	4	1	34	"	II	Tr. In.
		2	20	"	II	Sh. In.
		3	51	"	II	Tr. Eg.
		4	20	"	I	Tr. In.
		4	41	"	II	Sh. Eg.
		4	44	"	I	Sh. In.
	5	1	31	"	I	Oc. Dis.
		4	07	"	I	Ec. Re.
		3	37	P. M.	III	Tr. In.
		5	06	"	III	Tr. Eg.
		5	17	"	III	Sh. In.
		7	06	"	III	Sh. Eg.
		8	15	"	II	Oc. Dis.
		10	46	"	I	Tr. In.
		11	13	"	I	Sh. In.
		11	25	"	II	Ec. Re.
	6	12	57	A. M.	I	Tr. Eg.
		1	25	"	I	Sh. Eg.
		7	57	P. M.	I	Oc. Dis.
		10	36	"	I	Ec. Re.
	7	3	39	"	II	Sh. In.
		5	00	"	II	Tr. Eg.
		5	12	"	I	Tr. In.
		5	41	"	I	Sh. In.
		6	00	"	II	Sh. Eg.
		7	23	"	I	Tr. Eg.
		7	54	"	I	Sh. Eg.
	8	5	05	"	I	Ec. Re.
	11	3	51	A. M.	II	Tr. In.
		4	58	"	II	Sh. In.
	12	3	16	"	I	Oc. Dis.
		6	55	P. M.	III	Tr. In.
		8	28	"	III	Tr. Eg.
		9	18	"	III	Sh. In.
		10	30	"	II	Oc. Dis.
		11	07	"	III	Sh. Eg.
	13	12	31	A. M.	I	Tr. In.
		1	08	"	I	Sh. In.
		2	00	"	II	Ec. Re.
		2	42	"	I	Tr. Eg.
		3	20	"	I	Sh. Eg.
		9	42	P. M.	I	Oc. Dis.
	14	12	31	A. M.	I	Ec. Re.
		5	00	P. M.	II	Tr. In.
		6	18	"	II	Sh. In.
		6	57	"	I	Tr. In.
		7	18	"	II	Tr. Eg.
		7	37	"	I	Sh. In.
		8	39	"	II	Sh. Eg.
		9	09	"	I	Tr. Eg.
		9	49	"	I	Sh. Eg.
	15	4	09	"	I	Oc. Dis.
		7	00	"	I	Ec. Re.
Dec.	16	3	18	P. M.	II	Ec. Re.
		3	35	"	I	Tr. Eg.
		4	18	"	I	Sh. Eg.
	19	10	26	"	III	Tr. In.
		11	53	"	III	Tr. Eg.
	20	12	46	A. M.	II	Oc. Dis.
		1	18	"	III	Sh. In.
		2	16	"	I	Tr. In.
		3	03	"	I	Sh. In.
		3	08	"	III	Sh. Eg.
		11	29	P. M.	I	Oc. Dis.
	21	2	27	A. M.	I	Ec. Re.
		7	21	P. M.	II	Tr. In.
		8	43	"	I	Tr. In.
		8	56	"	II	Sh. In.
		9	31	"	I	Sh. In.
		9	41	"	II	Tr. Eg.
		10	55	"	I	Tr. Eg.
		11	17	"	II	Sh. Eg.
		11	44	"	I	Sh. Eg.
	22	5	56	"	I	Oc. Dis.
		8	56	"	I	Ec. Re.
	23	1	56	"	II	Oc. Dis.
		3	10	"	I	Tr. In.
		3	15	"	III	Ec. Dis.
		4	00	"	I	Sh. In.
		4	52	"	III	Ec. Re.
		5	22	"	I	Tr. Eg.
		5	54	"	II	Ec. Re.
		6	13	"	I	Sh. Eg.
	24	3	25	"	I	Ec. Re.
	27	1	40	A. M.	III	Tr. In.
	28	1	16	"	I	Oc. Dis.
		9	43	P. M.	II	Tr. In.
		10	30	"	I	Tr. In.
		11	26	"	I	Sh. In.
		11	35	"	II	Sh. In.
	29	12	03	A. M.	II	Tr. In.
		12	42	"	I	Tr. Eg.
		1	39	"	I	Sh. Eg.
		1	56	"	II	Sh. Eg.
		7	43	P. M.	I	Oc. Dis.
		10	52	"	I	Ec. Re.
	30	3	15	"	III	Oc. Dis.
		4	16	"	II	Oc. Dis.
		4	57	"	I	Tr. In.
		5	00	"	III	Oc. Re.
		5	55	"	I	Sh. In.
		7	09	"	I	Tr. Eg.
		7	17	"	III	Ec. Dis.
		8	08	"	I	Sh. Eg.
		8	29	"	II	Ec. Re.
		8	54	"	III	Ec. Re.
	31	2	11	"	I	Oc. Dis.
		5	20	"	I	Ec. Re.

In. denotes ingress; Eg. egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow. Only the phenomena visible in the United States are given. The times are Central Standard.

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

R. A................$0^h 52^m 32^s$
Decl..................+81° 17′
Period............*2d* $11^h 50^m$

Dec. 6	3 A. M.
11	2 "
16	2 "
21	2 "
26	1 "
31	1 "

ALGOL.

R. A...............$3^h 1^m 1^s$
Decl.................+ 40° 32′
Period............*2d* $20^h 49^m$

Dec. 10	4 A. M.
13	1 "
15	9 P. M.
18	6 "
30	6 A. M.

λ TAURI.

R. A........... ....$3^h 54^m 35^s$
Decl..................+ 12° 11′
Period.............*3d* $22^h 52^m$

Dec. 4	4 P. M.
8	3 P. .M

R. CANIS MAJORIS.

R. A.............. $7^h 14^m 30^s$
Decl........ ....— 16° 11′
Period......... ..*1d* $3^h 16^m$

Dec. 6	5 P. M.
7	8 "
8	11 "
10	3 A. M.
11	6 "
14	4 P. M.
15	8 "
16	11 "
18	2 A. M.
19	6 "

R. CANIS MAJ. CONT.

Dec. 23	6 P. M.
24	10 "
26	1 A. M.
27	4 "

S CANCRI.

R. A............ $8^h 37^m 39^s$
Decl.................+ 19° 26′
Period............*9d* $11^h 38^m$

Dec. 1	5 P. M.
10	5 A. M.
19	5 P. M.
29	4 A. M.

S ANTLIÆ.

R. A............. $9^h 27^m 30^s$
Decl...............— 28° 09′
Period........... *0d* $7^h 47^m$

Dec. 1	10 P. M.
2	6 A. M. 9 P. M.
3	5 A. M. 9 P. M.
4	5 A. M. 8 P. M.
5	4 A. M. 7 P. M.
6	3 A. M. 6 P. M.
7	3 A. M. 6 P. M.
8	2 A. M.
9	1 " midn.
10	midn.
11	11 P. M.
12	10 "
13	6 A. M. 9 P. M.
14	6 A. M.

S. ANTLIÆ CONT.

Dec. 14	9 P. M.
15	5 A. M. 8 P. M.
16	4 A. M. 7 P. M.
17	4 A. M. 7 P. M.
18	3 A. M 6 P. M.
19	3 A. M. 6 P. M.
20	2 A. M.
21	1 A. M.
22	1 A. M. midn.
23	midn.
24	11 P. M.
25	10 "
26	6 A. M. 9 P. M.
27	6 A. M. 8 P. M.
28	5 A. M. 8 P. M.
29	4 A. M. 7 P. M.
30	3 A. M. 6 P. M.
31	3 A. M. 6 P. M.

U. CORONÆ.

R. A ....$15^h 13^m 43^s$
Decl............... + 32° 03′
Period........... *3d* $10^h 51^m$

Dec. 11	5 A. M.
18	3 "
24	midn.

COMET NOTES.

We give below Mr. Brooks' account of the discovery of a new comet on the morning of Oct. 17. It was announced in the usual way by telegraph on that date. We have not been able to see the comet at Northfield on account of bad sky and the increasing moonlight, but hope that it has been observed sufficiently elsewhere to enable us to compute a rough orbit and find the comet when it comes out of the moonlight. A newspaper paragraph states that Mr. Brooks observed the comet on the morning of Oct. 22, and found it brighter than at the time of discovery. The tail could be traced to a distance of three degrees from the head. The position of the comet was given as R. A. $12^h 20^m$, Decl. +16° 12′, which would indicate that the comet was moving almost due north.

Discovery of Comet *c* 1893 (Brooks).—While sweeping the Eastern heavens this morning, which were unusually clear, it was my pleasure to discover a new telescopic comet. Position Oct. 16th, 16ʰ St. M. T. R. A. 12ʰ 21ᵐ, Decl. north 12° 55′. Motion slow in a northeasterly course. The comet is bright in the 10-inch equatorial and has a short tail. WILLIAM R. BROOKS.

Smith Observatory, Geneva, N. Y., Oct. 17, 1893.

Elements and Ephemeris of Comet 1893 II (Rordame-Quennisset).—From *Astr. Nach.* No. 3192 we take the following elements and ephemeris by Professor V. Cerulli of Teramo, Italy. The orbit does not differ perceptibly from a parabola. It is doubtful whether the comet can be seen in the morning twilight, yet it is possible that some keen-eyed observer may find it again.

ELEMENTS.

$T =$ 1893 July 7.31234 Berlin M. T.

$$\left.\begin{aligned} \omega &= 47^\circ\ 07'\ 37.0'' \\ \Omega &= 337\ \ 20\ \ 23.6 \\ i &= 159\ \ 57\ \ 58.3 \end{aligned}\right\}\ 1893.0$$

$\log q = 9.829020$

EPHEMERIS.

Berlin Midnight.	App. R. A. h	m	s	App. Decl. °	′	″	log Δ	Aberration. m	s
Nov. 1	12	45	32.03	+0	38	30.4	0.4715	24	37
3		45	53.06		32	26.8			
5		46	11.77		26	44.8	0.4727	24	41
7		46	28.01		21	24.9			
9		46	41.65		16	27.8	0.4732	24	43
11		46	52.56		11	54.0			
13		47	00.59		07	44.0	0.4730	24	42
15		47	05.60		03	58.2			
17		47	07.45	+0	00	37.2	0.4722	24	39
19		47	06.01	−0	02	18.4			
21		47	01.14		04	48.0	0.4708	24	34
23		46	52.71		06	51.3			
25		46	40.55		08	27.4	0.4687	24	27
27		46	24.50		09	35.6			
29	12	46	04.41	−0	10	15.3	0.4661	24	19

Ephemeris of Comet 1892 III, (Holmes) by Charles S. Benton.

(From A. J., No. 305).

	Gr. M. T. 1893	R. A. h	m	s	Decl. °	′	″	log Δ
Nov.	6.5	8	39	18.8	+35	10	52	0.5402
	8.5		39	45.3		13	42	
	10.5		40	06.6		16	47	
	12.5		40	22.6		20	08	
	14.5		40	33.2		23	43	0.5292
	16.5		40	38.4		27	33	
	18.5		40	38.1		31	36	
	20.5		40	32.3		35	52	
	22.5		40	21.0		40	20	0.5187
	24.5		40	04.0		45	00	
	26.5		39	41.5		49	48	
	28.5		39	13.3		54	47	
	30.5		38	39.3	35	59	52	0.5089
Dec.	2.5		37	59.7	36	05	04	
	4.5	8	37	14.4	+36	10	20	

		R. A.			Decl.			log Δ
1893.		h	m	s	°	′	″	
Dec.	6.5	8	36	23.5	+ 36	15	42	
	8.5		35	27.0		21	03	0.5002
	10.5		34	25.2		26	24	
	12.5		33	18.0		31	43	
	14.5		32	05.1		36	59	
	16.5		30	48.3		42	08	0.4932
	18.5		29	26.0		47	09	
	20.5		27	59.1		51	59	
	22.5		26	27.8	36	56	38	
	24.5		24	52.4	37	01	03	0.4882
	26.5		23	13.0		05	13	
	28.5		21	30.0		09	04	
	30.5		19	43.6		12	38	
'94 Jan.	1.5	8	17	54.1	+ 37	15	46	0.4857

NEWS AND NOTES.

It is evidently hard for some of our subscribers to remember that this journal is published only ten times a year. July and September are uniformly vacation months. For twelve years this decimal system of publishing has been in use. The consecutive numbers of any volume will be found on the first page of the cover.

It is also latterly the custom of the publisher to inform subscribers promptly of the expiration of paid subscriptions, so that it may be known at once if it is their wish to continue the subscription. Neither of our publications will be sent to any one knowingly without orders for so doing. When letters of inquiry are sent, it is to be hoped that patrons will respond promptly that we may not be in doubt as to their wishes.

The second plate of the Corona by Professor J. M. Schaeberle which was to accompany his article in the last number was a failure on the part of the photogravure company entrusted to reproduce it. The bad feature in the case was that we were not notified of the failure until five days after the time the work was promised. Still worse, fifteen days later, we were informed that the company had given up the job entirely. We then did not have time to get the reproduction made elsewhere for this issue. We will try other artists in the hope of bringing out the beautiful long exposure plate by Professor Schaeberle which has been placed in our hands for this purpose. There is much of detail in the outer corona on this positive that we fear it will not be possible to reproduce. It is a worthy companion plate for that published last month.

Mounting of Telescope for Manila Observatory.—In the notes on a new Observatory for Manila published in our last issue, it was stated that the telescope being mounted for that Observatory by G. N. Saegmuller of Washington, D. C., is to be built on the same plan as the 12-inch at the new Naval Observatory and that it was designed by Professor W. Harkness of the Naval Observatory.

Mr. Saegmuller informs us that this statement is erroneous. We are glad to correct it. The facts are, the mounting for the Manila telescope differs very materially from the 12-inch at the Naval Observatory, and secondly, Professor Harkness did not design it. As inspector of the work Professor Harkness made some changes in the plans and drawings which Mr. Saegmuller submitted; he placed the adjustment for azimuth and latitude on the head instead of on the base; he added the solar and lunar speed to the clock and placed the latter in the middle of the column instead of near the top.

In fact the 12-inch at the Naval Observatory is built on the same general plan as the two telescopes of the same size which Mr. Saegmuller designed and built for Georgetown College and Ladd Observatory respectively several years ago.

Professor Young observes Jupiter's Fifth Satellite.—I write to say that the new satellite of Jupiter was observed here by Professor Reed and myself on last Saturday night—Oct. 7-8. The atmospheric conditions were not very good, and the satellite was very faint—visible only at times, but then with perfect certainty. It was not possible to secure any micrometer measures, but we agreed in estimating the time of western elongation as between $12^h\ 35^m$ and $12^h\ 45^m$ eastern time. Marth's ephemeris would put it at $12^h\ 31^m$, so that the satellite appears to be some 9 or 10 minutes behind time. This agrees very closely with the result of Barnard's earlier observations of Sept. 15-16, which have just reached us in the *Astronomical Journal.* C. A. YOUNG.

Princeton, N. J., Oct. 12, 1893.

Comet 1889 V in Jupiter's Satellite System.—In Nos. 302 and 303 of the *Astronomical Journal*, Dr. Charles Lane Poor discusses the orbit of Comet 1889 V with special reference to its passage through Jupiter's system in July, 1886. He concludes (No. 302, page 126) that the comet was 2.65 days within the system of Jupiter's satellites, and during this time it made nearly a complete circuit about the planet, passing over an arc of 313° of longitude. It passed its peri-Jove July 20.10 Greenwich mean time, at a distance of about 100,000 miles from Jupiter's center and in a longitude of about 275°.

It occurs to me that a comparatively slight force at this time would suffice if properly directed to cause a portion of the comet to be detached and to pursue an elliptical orbit around Jupiter. Such eruptive forces are common to comets at perihelion and would probably exist at such a close peri-Jovian passage. Does this furnish a possible origin of Jupiter's fifth satellite?

The small inclination of the comet's orbit, 6°, and the sufficiently close agreement of its peri-Jovian distance with the distance of the satellite, 112,000 miles, are favorable to this view, as also is the fact that the comet's motion around Jupiter was direct.

The question then arises—was the satellite in longitude 275° on this date? A question not so easily answered, since an uncertainty of 1 sec. in its periodic time, carried back to 1886 would cause an uncertainty of 36° in the satellite's longitude, to say nothing of perturbations by the other satellites which must be considerable. J. A. PARKHURST.

Dudley Observatory.—When the new Dudley Observatory is completed we are promised a cut of it and detailed description. In the New York *Times* of Sept. 10 will be found a two-column article with a good etching of the Observatory building and a historical statement of the founding, growth and present rebuilding of this prominent Observatory.

While it is yet too "early to speak of the instruments of the Observatory in detail, it may be said that the telescope is, however, mounted and nearly in adjustment, and has been tested on second-rate nights to an extent sufficient to show that its performance will be excellent. The objectives are 12.2-inches aperture, and there are three of these lenses. The back lens, crown glass, is common to both visual and photographic combinations, for each of which a flint front lens is provided. The focal length is 180 inches for the visual combination, and 162 inches for the photographic. There is a 4.5-inch guiding telescope attached to the main tube. The focal length of this 160 inches. There is also an excellent finder of 3 inches aperture."

"Among those who have contributed to the re-founding of the Observatory, as given in the paper before referred to, are Mrs. William L. Rice, Mrs. Catherine Gansevoort Lansing, Mrs. Anna Parker Pruyn and her daughter, Miss Huybertie Lansing Pruyn, of Albany, N. Y. Prominent among the other subscribers to the fund are Dean Sage, Samuel B. Ward, the heirs of Charles B. Lansing, James B. Jermain, E. G. Benedict, Grange Sard, Frederick Townsend, W. L. Learned, and John G. Myers, all well-known residents of Albany."

"The support of the Observatory is derived from an invested fund which yields an annual income of $5,000. The annual expenditure of the Government Observatory is about $60,000, and the annual income of the Harvard College Observatory is well above $40.000. The resources of the Dudley Observatory, notwithstanding its excellent facilities for work and its refined instruments, are thus manifestly far below those of an Observatory of the first rank in this respect. Yet it is the only astronomical Observatory in the imperial state of New York for which there is independent and permanent provision for astronomical investigations."

Dorothea Klumpke.—We regret exceedingly that our proof reader was so much at fault as to allow an error in the spelling of Dorothea Klumpke's name as it appears in her paper printed elsewhere. There is no good reason for a mistake in the name of one so well known as Dorothea Klumpke, the Directress of the Bureau of Measurements of Paris Observatory.

It may be added that the same person is undoubtedly meant in the following paragraph which we clip from one of our eastern papers:

> "A recent issue of the Paris *Figaro* devotes half a column to an enthusiastic account of a young American girl named Klumpke, who has won for herself recognition as one of the most learned astronomers and most indefatigable and successful observers in France Five years ago she was received as a pupil in the *Observatoire* Since then a few other women have been allowed to join in the work carried on in that world-famous institution, but she was the first to whom the doors were opened, and for a long time she was the only one.

Parallax of Webb's Planetary Nebula, B. D. + 41°.4004.—During the summer of 1892 Dr. J. Wilsing of Potsdam Observatory began a series of photographs of Webb's planetary nebula, B. D. + 41°.4004, using the new refractor, with the intention of determining the parallax of the nebula. No. 3190 *Astronomische Nachrichten* gives an account of the measurements made. Six stars were used for comparison, and the distance of the nebula was measured from two of these stars, the others being used for finding the value of the measured distances in seconds of arc, etc.

The relative parallax comes out negative, and shows, as Dr. Wilsing thinks, that the distance of Webb's nebula from the Sun can not be assumed in any way to be less than the distances of both the eleven magnitude comparison stars.

Dr. Janssen's Visit to the Observatory on Mont Blanc.—In *Nature* (October 5), is given a fuller account of Dr. Janssen's recent visit to the Observatory on Mont Blanc, than that found elsewhere under Astro-physical Notes. We copy that account for the sake of further facts of general interest found in it. It is as follows:

"We left Chamonix on September 8, at 7 A. M., and arrived at the summit on September 11, at 2:30 P. M. The Observatory was then in front of us. The construction has several floors, of which the framework, formed by large and massive beams crossed in all directions in order to ensure the rigidity of the whole, produces a deep impression upon the mind. One wonders how it has been possible to transport the edifice to this altitude and fix it on the snow. However, if the conditions offered by the hard, permanent, and little mobile snows of the summit are carefully considered, it is soon recognized that the snows are able to support very considerable weights,* and that they will be only slightly amenable to displacements, which will render it necessary to straighten again the construction which has been fixed upon them.

"On my arrival I made a rapid survey, and saw that the construction had not been sunk in the snow as much as I had stipulated of the contractors. I do not approve of this. My guides and myself then took possession of the largest underground room. I intended at first to fix the instruments for enabling observations to be commenced immediately, and the provisions were left on the Rocher-Rouge. This circumstance put us in a state of perplexity, for the weather suddenly became very bad, and we had to remain two days separated from the stores. The storm lasted from Tuesday until Thursday morning. Beautiful weather then set in and I was able to begin the observations.

"The observations have for their principal object the question of the presence of oxygen in the solar atmosphere. The Academy knows that I worked at this important point during my ascensions to the Grands-Mulets (3050 meters) in 1888, and at M. Vallot's Observatory in 1890.

"But the novelty of the observations of 1893 lies in the fact that they have been effected on the very summit of Mont Blanc, and that the instrument employed is infinitely superior to that of the two preceeding ascensions. At the first, in fact, a Duboscq spectroscope incapable of separating the B group into distinct lines was employed, while the instrument about to be employed at the summit of Mont Blanc is a grating spectroscope (the dispersive piece of which I owe to the kindness of Rowland), with telescopes having a focal length of 0 75 and showing all the details of the B group. The circumstance is of considerable importance, for it may lead to the discovery, in the constitution of the group in question, of valuable elements for measuring in some way the effects of the diminution of the action of our atmosphere as one ascends into it, and, accordingly, to determine whether this diminution extends to total extinction at its limits. In fact we shall learn whether or no the double lines which make up the B group diminish in intensity as their refrangibilities diminish; that is, as their wave-lengths increase.

"This circumstance may perhaps be employed with profit, if not to measure, at least to observe the diminution of the action of the selective absorbtion of our atmosphere. It has been ascertained that the most feeble doubles fade away one after the other as the atmosphere is ascended, that is to say, as the absorbing action is diminished, Thus, under ordinary circumstances, at the surface of our seas or upon our plains, thirteen or founteen doubles can be seen, not reckoning that which is known as the head of B.

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* See *Comptes Reudus* for an account of experiments made at Meudon on the resistance of slightly compressed snow.

"But even at Chamonix, that is at an altitude of 1050 metres, the thirteenth double is very difficult to make out, and at the Grand Mulets (3050 m), it is only possible to see from the tenth to the twelth, while at the summit of Mont Blanc I could hardly go beyond the eighth.

"It is not to be supposed that we establish a proportionality between the numerical diminution of the doubles and that of the atmospheric action. The law is evidently of a much more complex character. But this diminution, especially when considered in connection with the experiments made with tubes full of oxygen, and able to reproduce the series of atmospheric phenomena to which we have referred, is sufficient for us to conclude that the B group would totally disappear at the limits of our atmosphere. It is remarkable, however, that if we take the coefficient 0.566 that represents the diminution of the atmospheric action at the summit of Mont Blanc according to barometric pressures and multiply it by thirteen—the number that represents the doubles clearly visible on the plain—we obtain 7·4 as the result; that is to say, very nearly the number (8) doubles that can be seen by me on the summit of Mont Blanc.

"This result is certainly remarkable, but I repeat that, in my opinion, it is only by the comparison with tubes reproducing the same optical conditions as nearly as possible, that any definite conclusions will be obtained. These comparative experiments have already been commenced in the laboratory of Meudon Observatory, and they lead to the same result, viz., the disappearance of the groups A, B, and α at the limits of the atmosphere. On account of the importance of the question, however, the experiments will be repeated and completed.

"The question arises as to whether the high temperatures to which solar gases and vapors are subjected are not capable of modifying the power of selective absorbtion, and particularily whether the absorbtion of oxygen which takes place in the sun's atmosphere would not be altogether different from that indicated by the experiments which have been made at ordinary temperatures.

"I have already instituted experiments with the idea of replying to this objection. I shall give an account of them to the Academy in due course, but I may say that the absorbtion spectrum of oxygen, either the line spectrum or the unresolvable bands, do not appear to be modified in an appreciable manner when the oxygen is raised to temperatures of about 400 or 500 degrees.

"On the whole, I think that observations made on the summit of Mont Blanc give a new and much sounder foundation to the study of the question of the purely telluric origin of the oxygen groups in the solar spectrum, and lead to the conclusions previously stated.

"Independently of these observations I have also given some attention to the transparency of the atmosphere of this almost unique station, and to the atmospheric phenomena which are included in such an extensive view, and across such a great thickness. I shall speak of this on a future occasion.

"The Observatory, of course, is not completed. There yet remains much to be done independently of interior arrangements and the installation of the instruments; but the great difficulty has been overcome, for we are free to work, and no longer have to reckon with the snowstorms; the rest will follow in due course.

"I hope that the Observatory will soon be able to offer a much more comfortable sojourn than I have had there; but that will depend upon the weather. Be this as it may, I regret nothing. I strongly wished to see our work in position, and still more fervently desired to inaugurate it by observations which are ever in my mind. I am fortunate at having been able to realize my desires in spite of some difficulties."

The Change of Sensitiveness in Dry Plates.—We quote some exceedingly interesting and useful remarks on the subject of dry plates in astronomical photography from a paper* by Professor Max Wolf of Heidelberg University:

"* * It is not a pleasant experience to give an eight or nine hours' exposure to what is believed to be a highly sensitive plate, and then to find on development that the whole work has been thrown away, because the plate was really quite an insensitive one. The photographer who has had this experience repeated several times (as I have), very soon learns to become cautious. The only reliable test of sensitiveness, however, as I may here remark, is comparison by actual exposure to stars, the ordinary sensitometer tests being much too uncertain.

"Special caution is necessary in dealing with fresh plates. In the early part of my work I always noticed that new plates received from the makers were uniformly less sensitive than the previous ones, and that it was necessary to expose them a much longer time, so that it almost seemed as if the manufacture of dry plates was retrograding. * * The peculiarity is so strongly marked that during the last winter I was hardly able to obtain the same objects on a new lot of Lumiére plates that I had previously obtained with the last plates of the same make, even with a three-fold greater exposure. * *

"I had, indeed, known earlier than this that plates changed somewhat in sensitiveness when stored, but I could hardly expect that the change would amount to so much as a three-fold increase; and yet it was so. After five months the new Lumiére plates, at first so slow, were as sensitive as the preceding ones, and exceeded in sensitiveness all my other plates. A similar change took place in those of other makers. * *

"The sensitiveness does not by any means increase indefinitely with the time. On the contrary, it soon reaches a maximum, which persists for some time, and after this the sensitiveness diminishes. * *

"For Lumiére plates this time has been found to be from five to seven months after manufacture. By taking advantage of this fact much can be gained; sometimes, as I have said, an increase in sensitiveness of three or four times. * *

"From the foregoing the astronomer may take warning never to assume that plates made from the same emulsion are equally sensitive if they are used at different times. * * For the same reason it is also very difficult to determine beforehand what exposure should be given in order to obtain stars of a certain magnitude. It is quite impossible to do this (leaving out of the question changes in the transparency of the air), without taking into account the age of the plates."

W. W. C., in Pub. 31, A. S. P.

To the Editors of Astronomy and Astro-Physics:

GENTLEMEN: In your number for August, 1893, page 664, is an extract from a letter of Dr. Joseph Morrison, in which occurs the following sentence:—"In 1884 I was elected a Fellow of the Royal Astronomical Society of England, a higher position than Professor Newcomb has in that learned Society." . . As it is possible that the words may give rise to a misapprehension, among those unacquainted with the constitution of our society, as to the relative position of our Fellows and Associates, I beg to point out that associates, of whom Professor Simon Newcomb is one, must be, in the words of the Bye-Laws, "*persons eminent in the science of Astronomy*." They are elected *honoris causa* on the invitation of the Council, in recognition of their distinguished services to astronomy.

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* The English translation in ASTRONOMY AND ASTRO-PHYSICS for August, from the original in Eder's *Jarbuck fur Photographie und Reproductions-Technik*.

Our Fellows, on the other hand, are, persons "desirous of admission into the Society," from whom no other scientific qualification is required than a genuine interest in astronomy. They have to state that they are desirous of being elected Fellows, and on election they pay an admission fee and annual contribution.

I should further state that Dr. Morrison is no longer a Fellow of the Society. His name was removed from the list of Fellows in 1891 in accordance with the Bye-Laws of the Society.

I am gentlemen,
Your obedient servant,
H. H. TURNER, Secretary.

Professor George E. Hale of Chicago University, editor of the department of Astro-Physics, is already on his way to Europe. His purpose is to spend some time in the study of particular themes by original research pertaining to his dement of science.

Double Star Astronomy.—In the current numbers of *The Observatory* Mr. T. Lewis is giving a series of articles on Double Star Astronomy. In the October number he writes on methods of calculating orbits of binary stars and on personal equation in double star measures. These articles will perhaps do good in exciting new interest in double star measurements, a field of work which has largely been adandoned for the newer work in photography and spectroscopy. It is to be hoped that a few observers with suitable telescopes will keep to this work, for we are now just getting to the point where the orbits of binaries can be computed with a reasonable degree of accuracy.

New Asteroids.—Since our last note on the asteroids in May number of ASTRONOMY AND ASTRO-PHYSICS, fifteen have been discovered, all by means of photography. 1893 AF has been identified with 158 Corona.

Designation.	Discovered by	Date of Photograph.	Magnitude.
1893 Y	Wolf	April 14	13
Z	Charlois	May 19	12
AA	Charlois	" 20	11
AB	Charlois	" 20	13
AC	Charlois	July 14	12
AD	Charlois	" 16	11
AE	Borrelly	" 5	12
AF	Charlois	Aug. 11	12
AG	Charlois	" 17	11
AH	Charlois	" 19	10
AJ	Charlois	Sept. 15	12
AK	Charlois	" 18	12
AL	Charlois	" 18	11
AM	Charlois	" 18	12
AN	Charlois	" 20	11.5

Astronomical and Physical Society of Toronto.—The last regular meeting of the Astronomical and Physical Society of Toronto was held in the society's rooms, No. 19 McGill street. The attendance was large and included several strangers, who were made welcome. The chair was occupied by Dr. Larratt W. Smith, Vice President. A new feature is the presentation to the society by outsiders of books and valuable papers, some of them rare. At a recent meeting a copy of Ferguson's Astronomy, printed in 1758, in two volumes, became the property of the society, but the third volume, containing the plates, was wanting. By a curious coincidence the volume necessary to make the set complete was donated at the last meeting by a friend who was unaware of the earlier presentation. The first number of Popular Astronomy, an illustrated monthly magazine published entirely in the interests of amateur astronomers, was laid on the table. It was highly praised by those members who examined it. It seems to be all and more than the publishers promised. The contributions are by the best writers and include easy papers on "Constellation Study," "The Spectroscope and some of its Applications," "The Moon," "The Asteroids and Their Relation to the Planetary System," "Concerted Observation of the Aurora," "Jupiter's Comet Family," "Astronomy with a Small Camera," "Nebula and Comet Seeking," "A Lesson on the Harvest Moon," "Shooting Stars and How to Observe Them." In addition, there are valuable planet notes, planet tables, comet notes, general notes, and a description of the "Face of the Sky" for the month of issue. This monthly deserves a large circulation. It is published by Professor W. W. Payne, director of the Goodsell Observatory, Northfield, Minnesota. Under the head of observations, Mr. A. Elvins announced that Finlay's comet, a telescopic object, is visible near "the beehive" in constellation Cancer. Mr. J. R. Collins showed several excellent negatives of the Sun and Moon taken with a two-inch telescope, and Mr. A. F. Miller handed in a drawing of the solar disc, September 24, at 11 o,clock, showing accurately the position of the sun-spots and faculæ by projection, and, at the same time, the position angles and shapes of the numerous red prominences scattered around the Sun's limb and visible by the spectroscopic method. Mr. John A. Copland objected to the explanation that the obscuration of the Sun on Friday, the fifteenth of September, was due to smoke at high altitudes and said that observation with a telescope and good field glass "revealed dust-specks gyrating in the atmosphere, as do those observed in a Sun ray," and that "these motes were of uniform color, dull grey." He suggested the cause might have been particles floating in the air, into which they had been ejected by Mount Colima volcano, in Mexico, which some days previously had broken out with a terrific explosion.

BOOK NOTICES.

The Science of Mechanics; a Critical and Historical Exposition of its Principles, by Dr. Ernst Mach, Professor of Physics in the University. Translated from the Second German Edition by Thomas J. McCormack. Two hundred and fifty cuts and illustrations. Chicago: The Open Court Publishing Co., 1893, pp. 534. Price cloth $2.50.

Mach's Mechanics was first published in 1883 The author's aim then was to produce a book on this subject that should be treated as one of the physical sciences, and not primarily as a branch of mathematics. In 1888 the book passed through its second edition, and the translation before us is from this later edition.

In the introduction the general idea of the science of mechanics is stated. Instruction, knowledge and its relation to investigation and mechanical experiences are spoken of as very old, and references and illustrations from the Egyptian and Assyrian monuments are given. A brief discussion, concerning the origin of science, the nature of knowledge and its mode of communication, occupies the remaining part of the introduction.

The text proper begins with the development of the principles of statistics using the lever as the first theme. The new feature of treatment is the prominence given to the historical side of it. The earliest mechanical researches relating to statistics referred to were those of Archimedes, and enough is given to indicate his methods of work and the character and value of his results. His mode of view was modified by Galileo, but it was the modern Lagrange who showed how to study the lever in a concise way that revealed a practical mathematical perception. Huyghens' method is also presented and illustrated and with the others discussed by the author. This subject occupies fifteen pages. In a similar way are presented the inclined plane, the composition of forces, and virtual velocities, with a review of statistics as a whole.

The author then considers the principles of statistics in their application to fluids. also to gaseous bodies.

The second chapter treats of the development of Dynamics, first noticing Galileo's achievements, then the dispute of the Cartesians and Leibnitz followed by a description of Morin's apparatus. Under a second title are found the achievements of Huyghens presented in an attractive way, especially the pendulum clock that goes by his name.

A third title gives the work of Newton in discovering universal gravitation which is detailed quite fully. Also, under other sections are given Newton's views of time, space and motion, a synoptical critique of the Newtonian enunciations, and a retrospect of the development of dynamics.

The three remaining chapters are devoted respectively to the extended applications of the principles of mechanics and the deductive development of the science; the formal development of mechanics, and the relations of mechanics to other departments of knowledge. The book closes with an appendix, a chronological table of a few eminent inquirers and of their more important mechanical works, and an index.

We deem the book a very useful one, in that it gives the student some idea of the German method of study and topical work in elementary physics which will be helpful to those who are not already acquainted with them.

An Academic Arithmetic for Academies, High and Commercial Schools. By Webster Wells, S. B., associate Professor of Mathematics in the Massachusetts Institute of Technology. Messrs. Leach, Shewell & Sanborn, publishers, Boston, New York and Chicago, pp. 339.

This new book is the lowest in the Wells' mathematical series which has already become widely and favorably known. The more elementary part of the subject is about the same as usually found in good books in arithmetic. The statement of principle or rule is concise and the matter is arranged on the page in systematic way. Factoring and the tests by nines, afford useful practice. Young students ought to form habits of testing results in daily exercise. The illustrations in fractions are better than usual and will wear in the class-room. The attention given to the metric system and its applications and to mensuration in general is noteworthy. The practical bearing given to percentage, interest, discount, exchange, stocks, bonds and kindred subjects are some of the other points in its favor, The author has evidently taken pains in the selection of the matter and in the arrangement of this text-book to adapt it well to the place for which it is designed.

The Principles of Elementary Algebra. By N. P. Dupuis, M. A., F. R. S. C., Professor of Pure Mathematics in the University of Queen's College, Kingston, Canada. New York, Messrs. Macmillan and Co., 1892.

This book is intended to fill the place of an intermediate algebra, in the sense that it is not prepared for beginners, nor those who are proficient in the branch. Although this is true, it covers a fairly wide range of subjects from the elemental operations to the subject of determinants. The chapter on factors and factorization is suggestive of good methods for class drill. The titles of some of the chapters of this book give a fair idea of the breadth of the themes as they are presented. Fractions, ∞ and 0; ratio, proportion, variation and generalized proportion; concrete quantity, geometrical interpretations, the graph; undetermined coefficients and their applications; logarithms and exponentials; series and interpolation and elementary determinants.

The geometrical interpretation and the graph, so called, are certainly very helpful methods to aid the student in getting the meaning of some algebraic operations that are usually rather obscure.

The clear statement of points, the numerous examples and the range of subjects brought into a compass of 336 pages speak favorably for this text-book.

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Astronomy and Astro-Physics.

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General Astronomy.

ON A PRACTICAL METHOD OF DETERMINING DOUBLE STAR ORBITS BY A GRAPHICAL PROCESS, AND ON THE ELEMENTS ☊ AND λ.[*]

T. J. J. SEE.

In the present paper we propose to discuss briefly the methods of determining double star orbits, and to suggest certain modifications in the elements ☊ and λ ($= \pi -$ ☊), which seem desirable for the sake of uniformity. Since Savary's first attempt to find the orbit of a double star in 1827,[†] a number of other astronomers have proposed methods of great theoretical elegance and mathematical rigor for finding the orbits of double stars when the observations suffice to fix the apparent ellipse. The methods most deserving of mention are those of Encke,[‡] Herschel,[§] Thiele, Klinkerfues,[‖] Kowalsky,[¶] and Seeliger.[**]

As most of these methods are satisfactory theoretically, we shall here confine our attention to the practical work of determining orbits from data now furnished by observation, and shall suggest a short method which will give good practical results without lengthy calculations involving minute corrections not warranted by the present state of double star astronomy.

Sir John Herschel long ago introduced the use of graphical interpolating curves as a means of freeing the angles and distances from the accidental errors of observation. One axis was made to represent the time, the other the angle or distance.

Now it is evident that if the angles or distances changed slowly and uniformly with respect to the time, the curve of interpolation would flow smoothly and the flexure would be gradual. But it is well known that the radius vector of the companion describes

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[*] Read before the Congress of Astronomy and Astro-Physics, Chicago, Aug. 23, 1893.

[†] See the *Connaissance des Temps*, 1830, for the method in full.

[‡] *Berliner Jahrbuch*, 1832.

[§] Memoirs Royal Astronomical Society, Vol. V.

[‖] *Astr. Nachr.*, Vol. XLVII, p. 353, or Klinkerfues' *Theoretische Astronomie*, 1871.

[¶] See Glasenapp's paper in *Monthly Notices*, March, 1889.

[**] Dr. Schorr's *Inaugural Dissertation*, München, 1889.

equal areas in equal times, and as the apparent distances in different parts of the orbit are, in many systems, very unequal (owing to the various eccentricities and inclinations), it follows that the angles and distances will frequently change at very unequal rates with respect to the time. And as the rate of change is unknown there is no means of knowing what the curvature will be at a given point; so that the course of the graphical interpolation becomes uncertain, and the drawing of the curve is altogether a matter of judgment.

Hence, although Herschel may have regarded the graphical interpolating curves as advantageous devices at a time when the systems showed very little motion (and hence the *curvature* was not so uncertain as where the motion is great and unequal), it is very doubtful whether he would commend this method of interpolation at the present time.

We may also observe that the uncertainty as to the course of the true interpolating curve enters with full effect into the graphical normal places, and if we base the orbit on points thus determined the resulting path will often show a systematic deviation from the true ellipse. Hence such correction of observations is not only of doubtful value, but likely to lead to systematic errors which cannot be eliminated from the final result. If, on the other hand, we plat the observations directly (corrected only for the precession, if that is sensible), we shall obtain a series of points through which the trial ellipse must pass as a sort of interpolating curve, following the best observations. By means of an ellipsograph this apparent orbit can be drawn with geometrical precision and made to satisfy the observed distances and at the same time conform to the law of areas.

This trial ellipse is an interpolating curve which meets the conditions of the problem admirably, while it also renders the agreement of the observations with the proposed orbit singularly conspicuous to the eye. Moreover it avoids in a high degree the systematic errors incidental to graphical interpolation when the motion in angle and distance varies at different points of the orbit; hence when the trial ellipse has been carefully drawn it furnishes a suitable basis for the deduction of the true orbit by graphical methods such as those of Klinkerfues* and Ball.†

The great problem in double star astronomy is to find the apparent orbit, since when the apparent orbit is once found, there is no difficulty in finding the true orbit by means of formulæ based

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* *Theoretische Astronomie*, p. 392.

† *English Mechanic*. April 21, 1893.

upon the law of gravitation. It is assumed in the graphical method sketched above that the apparent orbit is drawn on a scale sufficiently large to prevent sensible error in the graphical work, and this can be secured by adopting a scale of convenient size, making the major axis of the apparent ellipse from 6 to 12 inches in length. The value of the elements will depend upon the agreement of the apparent ellipse with the observations. When this agreement is satisfactory, and the ellipse is geometrically perfect, the resulting elements will have the required degree of precision.

For a long time it has been customary to test the accuracy of double-star orbits by comparing the computed with the observed places, and to estimate the value of an orbit mainly by the residuals of position angle. Mr. Burnham's great practical experience with the micrometer has shown that distances (especially in case of close pairs) are quite as trustworthy as angles, and the method of finding an orbit solely by means of position-angles has been repeatedly discredited by absured results of computers who discard the measures of distance. The belief prevailing among astronomers early in this century that distances were necessarily less accurate than angles was probably due, in part at least, to the inaccuracy of the older micrometers, and to the circumstance that the older observers had measured chiefly angles. But since the epoch-making work of the Struves, Dembowski and Burnham, there is, of course, not the least foundation for this antiquated tradition. That distances should be given more weight in the determination of orbits than has been customary hitherto, is sufficiently established by the work of Mr. Burnham on numerous stars and by the researches of Otto Struve on the orbit of 42 Comæ Berenices (*M. N.* vol. XXXV, p. 370), which depends almost solely upon distances. We also observe that when the orbit is highly inclined upon our visual ray, distances must necessarily form the basis for the orbit, since the measures of position-angles are practically worthless, owing to the slow change of the angle and the wide range of errors of observation.

In general it is evident that the orbit should be based upon both angles and distances, and it is of the utmost importance that the apparent orbit should be compared directly with the platted measures, so that the representation of the observations can be seen at a glance. This is the line of procedure adopted in the graphical method, which is therefore the logical process of finding the true elements of binaries.

Some astronomers will doubtless consider that an orbit deduced by the method of Least Squares is much to be preferred to one deduced by the graphical method sketched above. That this is not the case with most systems as now known will be evident on recalling the existence in double-star measures of conspicuous systematic errors, which do not follow the laws of chance, and therefore can not be eliminated by the method of Least Squares. We should also remember that the theory of probability does not require the positive and negative residuals to vanish except when all *mistakes* are excluded, and the number of observations is increased beyond limit. Since in any actual case it is practically certain that these conditions are not fulfilled, even approximately, it is evidently of doubtful value to apply the method of Least Squares, except possibly in exceptional cases where the observations are very complete and accordant.

We are not here questioning the soundness of the method of Least Squares (for it is founded upon the philosophical principles of probability as laid down by Laplace and Gauss), but only doubting the propriety of applying the method where the conditions are wanting which underly the theory of Least Squares.

In the last 20 years frequent application has been made of Least Squares in double star astronomy, and in numerous cases we need only plat the observations with the resulting orbit to show the entire absurdity of the results obtained. Mr. Burnham has frequently called attention to the untrustworthy character of orbits of this nature, where the measures are few and scattering and of doubtful value; and we shall here merely remark that under such circumstances it is undoubtedly better not to apply the method of Least Squares at all. And in any event we certainly must not expect that the algebraic sum of the residuals will vanish. If the method of Least Squares can be advantageously used in research on double star orbits, it will be in cases where the number of observations is large and the measures are practically free from systematic error. The trial ellipse secures all that is sought by the method of least squares, and, in part at least, avoids the effects of systematic errors; while it also conveys a just conception of the uncertainty necessarily attending double star elements in the present state of our knowledge. On the other hand the small probably errors obtained by the method of Least Squares are likely to convey the impression of much greater accuracy than is possible with the rough data now available. Lastly, we may add that the simple graphical method is a great saving of time and labor, compared with the tedious method of a Least Square adjustment, which involves the formation and solution of a large number of normal equations. This graphical method was introduced into modern double star astronomy by Mr. S. W. Burnham, who has adopted it as the simplest and most practical means of finding orbits; but substantially the same method of representing measures was employed early in this century by William Struve.[*] It is somewhat remarkable that the most direct and practical of all methods should have been so much overlooked during the last half century, and we can only attribute this oversight to the undue importance assigned to the use of position-angles and to the adjustment of residuals by the method of Least Squares.

We shall now exhibit some of the orbits which we have recently obtained by the method sketched above, and from the agreement of the observations with the resulting orbits we shall be able to see what margin of uncertainty still remains in the elements of double stars.

[The speaker here exhibited the apparent orbits of γ Virginis, η Cassiopeiæ, α Canis Majoris, 70 Ophiuchi, ζ Cancri, η Coronæ Borealis, ξ Scorpii, Σ 3062, Σ 2173, 42 Comæ Berenices, β Delphini, ζ Herculis, ξ Ursæ Majoris, γ Coronæ Borealis, ω Leonis, γ Coronæ Australis, Σ 3121, μ^1 Herculis, μ^2 Böotis, and δ Equulei].

From the drawings which have been presented we see what degree of accuracy has been attained in double star work, and it is now evident that the graphical method is not only accurate enough for the finest requirements of modern measures, but the simplest and most logical method, and one which will therefore commend itself to working astronomers.

We shall now discuss the elements ☊ and λ. It is well known that the formulæ for determining the elements of the orbits of double stars do not enable us to distinguish between ascending and descending node.

Now as there are two nodes 180° apart, it follows that one of these nodes must necessarily fall between 0° and 180°; accordingly, this node will be taken as the ascending node,[§] and we shall reckon λ and u (argument of the latitude) from this node in the direction of the motion, from 0° to 360°. By this method of reckoning ☊ and λ and u, it will be easy to find the true anoma-

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[*] Mensuræ Micrometricæ, last plate.

[†] Spectroscopic application of Döppler's principle will eventually enable us to decide which is really the ascending node, where the companion moves towards the Earth relative to the central star.

lies when the arguments of the latitude have been computed; for we shall have $v = u - \lambda$, both for direct and retrograde motion.

The above method of reckoning Ω and λ will be very convenient for laying down the apparent orbit of a double star, from the elements, by the graphical method recently discovered and published in the ASTRONOMY AND ASTRO-PHYSICS (August, 1893), and it will, above all, bring consistency and uniformity where confusion now exists.

We believe that any slight inconvenience that may arise in case of analytical formulæ used by some computers can be easily overcome; but even if this be impossible, it will be easy to deduce the elements as formerly, and then to transform them into the system here suggested. The advantages of this way of reckoning for graphical purposes and the uniformity thus secured must be regarded as a sufficient defense of the innovation thus introduced.

THE UNIVERSITY OF CHICAGO,
1893, August 19.

NOTE:—The reader will see from the accompanying orbit of γ Virginis how the practical method above suggested is applied. The observations were taken from original sources, and include all the measures of any value hitherto published. From this mass of data, we formed means (usually yearly) based upon the measures of the best observers—such as Struve, O. Struve, Mädler, Secchi, Dawes, Dembowski, Englemann, Hall, Schiaparelli, Burnham, Perrotin, etc. These means were platted directly, and the accompanying orbit drawn by means of an ellipsograph.

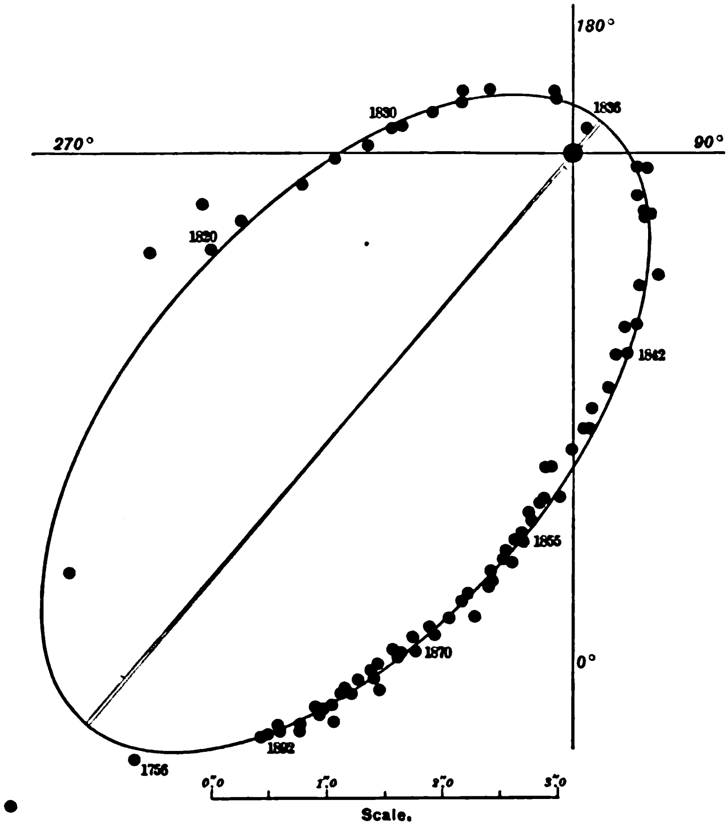
The elements of γ Virginis are:

$P = 192.07$ years.
$T = 1836\ 51$
$e = 0.895$
$a = 4''.1436$
$i = 34^\circ.12$
$\Omega = 54^\circ.90$
$\lambda = 274^\circ.23$
$u = -\ 1^\circ.87422$

Apparent Orbit:

Length of major axis $= 6''.86$
Length of minor axis $= 3''.65$
Angle of major axis $= 139^\circ.5$
Angle of periastron $= 139^\circ.8$
Distance of star from centre $= 3''.07$

The system of γ Virginis is remarkable for the great eccentricity of the orbit and for the equality of the components. As the parallax of the system has never been determined, we can not



γ Virginis = Σ 1670

give the absolute dimensions of the orbit, nor the combined mass of the components; but since the proper motion is considerable, there is reason to believe that the parallax is sensible, and, owing to the great interest attaching to the system, it ought to be determined. The orbital motion will be slow for a number of years, but the star will deserve occasional observation so that after apastron passage (about 1932) the elements may be made definitive.

THE UNIVERSITY OF CHICAGO,
1893, Oct. 24th.

THE SYSTEM OF ζ CANCRI.

S W. BURNHAM.

Professor Seeliger has reviewed at considerable length (A. N. 3165) his theory of the so-called dark star in the system of ζ Cancri, and criticised my paper in *Monthly Notices* (April, 1891) where I pointed out the weakness of the evidence on which this theory was based. No new facts have been advanced, and, so far as the original question is concerned, there is nothing which calls for any reply. I have given my views fully in the paper above referred to, and I see no reason for changing or modifying them in any respect; and it would add nothing to their force or value to repeat and emphasize them here. I wish only to call attention to a few points which Professor Seeliger seems to have overlooked.

I. This is not a question to be determined by an expression of opinion, however well fortified, or by adopting one of several explanations of apparently inconsistent observations. It is a simple matter of fact, and is to be established by direct evidence as in other instances of everyday occurrence. The matter stands now precisely where it did when the original paper on this subject was printed. No fact has been established since that time which can be construed to change or affect either side of the question.

II. Professor Seeliger must have read my paper in *Monthly Notices* somewhat superficially, or he would not have taken the trouble to argue that in the numerous examples which I cited of apparently variable motion, orbits should not be computed of invisible components of these systems. Of course this is correct, but that it could be done in some of these cases, and with the same propriety as in ζ Cancri, is sufficiently obvious from an inspection of the diagram I have given of the last named star, showing the observed positions side by side with the positions deduced from the theory of a disturbing body. If this latitude is allowable, then certainly there would be no difficulty in getting orbits from the measures of some of these pairs which would be on the same footing, and in every way as probable as that of ζ Cancri. I have pointed out that in all pairs of a certain class the observations show a variable motion of the companion. For the purposes of this case it is entirely immaterial whether these apparent variations are distributed regularly or otherwise. The fact that they uniformly exist is sufficient to at least throw great doubt on any theory of a disturbing body based upon them in an isolated example. The only logical and consistent conclusion would be that these examples of variable motion furnish additional proof of the probable soundness of the theory of dark stars. This claim is not made, and evidently for the reason that these and other instances which might be cited seem to prove too much.

III. It is evident that Professor Seeliger has had little practical experience in double star work, or he would not have criticised my remark that the close pair of ε Hydræ could not possibly affect the measures of C. The truth of this statement must be so obvious to every practical astronomer who is accustomed to use the micrometer that it can hardly be considered a debateable question.

IV. I have made no objection to any general theory of dark, and therefore invisible stars. For anything we know such bodies may exist anywhere in the stellar universe. I have only undertaken to show the insufficiency of the evidence at this time to establish the existence of any such body in the system ζ Cancri; and that a more natural and probable explanation can be offered for the apparent inconsistencies of the observations. Such dark stars may exist, and if so the fact can and will be established by incontrovertible evidence; but at present, from the unsatisfactory character of the proof, it cannot be regarded as anything more in this instance than a speculation.

V. After what I have done in the last twenty years in the way of the discovery of new members to previously known systems, I trust it is hardly necessary to say that personally I should be very glad to furnish evidence from actual measures which would establish beyond all question the existence of this fourth star; and to this end I have done what should have been done many years ago as the very first step in the investigation of this matter. In my first paper on this subject, I called attention to a method by which this supposed variable motion of *C* could be established, if it really existed; and in 1891 I commenced a series of measures in the way of comparing *C* with an outside star, thus eliminating all the sources of error which might affect the position of that star when measured from the close pair. I continued these measures for two years, and then, in consequence of leaving the Lick Observatory, was necessarily compelled to give up this and all other work with the micrometer. I therefore printed these observations (*Monthly Notices*, November, 1892), and expressed the hope that others would continue the work. Whether or not this has been done I am unable to say. I had taken it for granted that Professor Seeliger, if he had not already commenced the series of measures referred to, would at least continue the observations which in the course of a few years would settle the disputed question. Until this is done by some one, or some other reliable data is furnished, nothing is gained by re-opening, or further discussing the matter.

VI. Professor Seeliger's objection to this plan on the ground of its present incompleteness as compared with the old observations of C is valid, but it could hardly be insisted on by the advocates of this theory, since if the theory is sound it must be not only confirmed but established by this entirely independent evidence. At all events the objection would disappear by the continuance of the measures; and I had sufficient interest in ascertaining the truth, whatever it might be, to give the necessary time to the work while it was in my power to do so. The whole time necessary to make all these measures, even with an instrument as large and unwieldy as the 36-inch at Mt. Hamilton, would be less than two hours each year. The practical observer who is unwilling to spend this amount of time annually must be either remarkably busy, or have very little confidence and interest in the theory to betested. I sincerely hope that some experienced observer sometime will continue these measures for the few years necessary to settle this question. If there is any better or other way of making measures which shall help to decide the matter of variable motion, by all means let such observations be made. My only desire is to ascertain what the truth is.

CHICAGO, Sept. 1.

A NEW DISCUSSION OF PETERS' SERIES OF OBSERVATIONS TREATED BY PROFESSOR CHANDLER.*

F. FOLIE, DIRECTOR OF THE BELGIUM OBSERVATORY.

§ 1.

I was induced in 1890 to conclude from the interior fluidity of the terrestrial globe that the theoretical period of 305 days, calculated for a solid earth, could not be verified by observation; and taking half the difference of the R. A. or of the declination of the same star observed at the superior and inferior transits, or half

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* Intended for the Congress of ASTRONOMY AND ASTRO-PHYSICS, but received too late for presentation.

the sum of the latitudes obtained by both transits, I thought to have determined exactly a period of 337 days for the revolution of the astronomical pole round the geographical.*

Other works concerning that period, and those of Chandler particularly, have encouraged me to resume that subject.

In order to take advantage of the papers of this astronomer relative to the observations of Peters at Pulkova, I intended:

1st. To examine if the only application of the Eulerian nutation does not diminish the residuals of Peters' observations more than the formula of Chandler.

2d. To deduce from the same observations, by half the difference of the latitudes obtained by two superior and inferior consecutive transits.

(*a*) The coefficient of the diurnal nutation.

(*b*) The systematic velocity.

(*c*) The correction of the constant of the annual aberration.

I had beforehand determined, by means of the observations of Gyldén:

(*a*) The constants of the diurnal nutation.

(*b*) The systematical velocity.

(*c*) The correction of the constant of the aberration.

(*d*) The parallax of Polaris.

I shall make use of several results of this calculation in the reduction of Peters' observations, to which I shall apply the second procedure in order to diminish the number of the unknown, that without it, would be too considerable.

Let : Φ the height of the *geographical* pole, φ_s or φ_i the *astronomical* latitude determined by a superior or inferior transit by means of the usual formulæ of reduction.

z the correction of the mean adopted declination.

$\Delta\varphi$ the correction of the mean adopted latitude.

A the sum of the corrections that I adduce to the formulæ of reduction to the apparent declination not including the Eulerian nutation.

i the last correction for the superior transit.

$-i$ for the inferior.

We will have

$$\Phi = \varphi_s + z + A + i$$
$$\Phi = \varphi_i - z - A + i.$$

The half sum will give, calling φ_m that of the astronomical latitudes determined by both transits:

$$\Phi = \varphi_m + i.$$

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* Annuaire de l'Observatoire royal de Bruxelles pour 1891, pp. 266-274.

Let Φ_0 be the mean adopted latitude and

$$\varphi_m - \Phi_0 = n_1;$$

we shall have

$$\Delta\varphi = n_1 + i,$$

or, substituting for i, $u \sin \iota t + v \cos \iota t$, and for $\Delta\varphi$, ρ, w

$$u \sin \iota t + v \cos \iota t + \rho + n_1 = 0$$

In the half sum of the astronomical latitude determi consecutive transits, the one superior, the other inf errors of reduction then disappear, with exception ian nutation.*

In the half difference, this last disappears, but all main.

For the half difference gives

$$0 = \frac{\varphi_s - \varphi_i}{2} + z + A.$$

and, if

$$n_2 = \frac{\varphi_s - \varphi_i}{2}$$

$$0 = n_2 + z + A.$$

The whole of the corrections A comprise:

1st. The terms of the second order of the and of the nutation, of which no account has reductions; these terms may be put in the for

$$A_1 = -\tfrac{1}{4} \sin 2\delta (\Delta\alpha)^2, \dagger$$

$\Delta\alpha$ being the reduction to the apparent place.

I have added them to the residual n_2, whic

$$n'_2 = n_2 + A.$$

2d. The terms of the parallax, that I 0″.05, the value which I have deduced fr tions, and which Chandler also found fron

The new residuals thus become $n''_2 =$ have, putting $A = A_1 + A_2 + A_3$:

$$0 = n''_2 + W + A$$

3d. The terms of second order resulti of annual systematical aberration, the under the form:‡

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* *Loc. cit.*

† *Monthly Notices*, Vol. LII. p. 555.

* On the Formulæ of Reduction to Appar *Monthly Notices*, Vol. LII, No. 8, p. 555. By formula is written in M.N.: $KK'tg\delta(\cos\varepsilon \sin A$

$KK' \operatorname{tg} \delta \sin(A' - \alpha)(\cos \varepsilon \cos \alpha \cos \odot + \sin \alpha \sin \odot)$
the constant of the annual aberration, K' the reduced
that is projected on the equator, of the systematical
.
remark that the factor depending on ⊙ differs very
hat of the parallax.
being calculated by Nyrén, I have made use of it in
nomize time.
n $A' - \alpha = 260°$, that about corresponds to the
which I have deduced from Gyldén's observa-
that which the modern astronomers have deter-

$\delta = y.$

$- \alpha)(\cos \varepsilon \cos \alpha \cos \odot + \sin \alpha \sin \odot) = b'$

e to introduce in the preceding equation,
of which A_1 is composed, the term $b'y$;
which results from the correction x of the
n;
om the memoir of Nyrén.
iurnal nutation.
declination, under the form

$+ \alpha) \Sigma_1 + \cos (2L + \alpha) \Sigma_2],$

ent of the diurnal nutation, L the lon-
n (which passes through the axis of
f the terrestrial crust),
nctions, expressed in true longitudes

$+ 0.36 \cos 2\odot$
$\text{os}(2☽ - ☊) + 0.13 \cos(☾ - \Gamma)$
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he constant of the aberrations,

$x = + 0''.00095;$
$y = - 0''.035,$

Let Φ_0 be the mean adopted latitude and

$$\varphi_m - \Phi_0 = n_1;$$

we shall have

$$\Delta\varphi = n_1 + i,$$

or, substituting for i, $u \sin \iota t + v \cos \iota t$, and for $\Delta\varphi$, ρ, we have

$$u \sin \iota t + v \cos \iota t + \rho + n_1 = 0$$

In the half sum of the astronomical latitude determined by two consecutive transits, the one superior, the other inferior, all the errors of reduction then disappear, with exception of the Eulerian nutation.[*]

In the half difference, this last disappears, but all the other remain.

For the half difference gives

$$0 = \frac{\varphi_s - \varphi_i}{2} + z + A.$$

and, if

$$n_2 = \frac{\varphi_s - \varphi_i}{2}$$

$$0 = n_2 + z + A.$$

The whole of the corrections A comprise:

1st. The terms of the second order of the annual aberration and of the nutation, of which no account has been taken in the reductions; these terms may be put in the form

$$A_1 = -\tfrac{1}{4} \sin 2\delta(\Delta\alpha)^2, \text{ †}$$

$\Delta\alpha$ being the reduction to the apparent place in R. A.

I have added them to the residual n_2, which thus becomes

$$n'_2 = n_2 + A.$$

2d. The terms of the parallax, that I have made equal to 0".05, the value which I have deduced from Gyldén's observations, and which Chandler also found from those of Peters.

The new residuals thus become $n''_2 = n'_2 + A_2$, and we shall have, putting $A = A_1 + A_2 + A_3$:

$$0 = n_2'' + W + A_3.$$

3d. The terms of second order resulting from the combination of annual systematical aberration, these terms may be written under the form:[‡]

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[*] *Loc. cit.*

[†] *Monthly Notices*, Vol. LII, p. 555.

[*] On the Formulæ of Reduction to Apparent Places of Close Polar Stars. *Monthly Notices*, Vol. LII, No. 8, p. 555. By a mistake easy to discover, the formula is written in M.N.: $KK' tg\delta(\cos \varepsilon \sin A' \cos \odot - \cos A' \sin \odot)$.

$$-KK' \, tg\,\delta \sin(A' - \alpha)(\cos\varepsilon \cos\alpha \cos\odot + \sin\alpha \sin\odot)$$

K being the constant of the annual aberration, K' the *reduced* constant, that is *projected on the equator*, of the systematical aberration.

You will remark that the factor depending on $\odot$ differs very little from that of the parallax.

This last being calculated by Nyrén, I have made use of it in order to economize time.

I have taken $A' - \alpha = 260°$, that about corresponds to the value $A' = 277°$ which I have deduced from Gyldén's observations, and to that which the modern astronomers have determined.

Putting $KK'tg\delta = y$,

$$\text{and} - \sin(A' - \alpha)(\cos\varepsilon \cos\alpha \cos\odot + \sin\alpha \sin\odot) = b'$$

we will then have to introduce in the preceding equation, amongst the terms of which A_3 is composed, the term $b'y$;

4th. The term ax which results from the correction x of the constant of aberration;

a is also borrowed from the memoir of Nyrén.

5th. The terms of diurnal nutation.

I have put the last, in declination, under the form

$$\nu[-\sin(2L + \alpha)\,\Sigma_1 + \cos(2L + \alpha)\,\Sigma_2],$$

ν representing the coefficient of the diurnal nutation, L the longitude of the first meridian (which passes through the axis of least moment of inertia A of the terrestrial crust),

Σ_1 and Σ_2 the following functions, expressed in true longitudes of the Sun and of the Moon:*

$$\Sigma_1 = -1.155 - 0.134 \cos \text{☊} + 0.36 \cos 2\odot$$
$$+ 0.82 \cos 2\text{☽} + 0.14 \cos(2\text{☽} - \text{☊}) + 0.13 \cos(\text{☽} - I^{\mathrm{v}})$$

$$\Sigma_2 = -0.18 \sin \text{☊} + 0.39 \sin 2\odot$$
$$+ 0.89 \sin 2\text{☽} + 0.18 \sin(2\text{☽} - \text{☊}).$$

In the calculation of Peters' observations, which Chandler has combined by groups of several, I have been obliged to make abstraction of the lunar terms which must be calculated for each observation separately; I have taken account of them in those of Gyldén.

In order to avoid a too great number of unknown quantities, I have taken, in the calculation of Peters' observations, $L = 10^h$; whence

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* In my *Vraite des Reductions Stellaires*, the expressions of Σ_1 et Σ_2 are given in mean longitudes.

$$\sin(2L + \alpha) = -0.69, \quad \cos(2L + \alpha) = 0.71.$$

The coefficient ν of the diurnal nutation will then be multiplied by $C = 0.69\ \Sigma_1 + 0.71\ \Sigma_2$.

Substituting for A_3 the expressions 3d, 4th and 5th given above we shall have the equation of condition

$$ax + b'y + c\nu + z + n_2'' = 0.$$

§ 2.

In the application of the equations (I) and (II) to Peters' observations, I have thought proper to suppress those of 18th December, 1842, and of 2d December, 1843, which give residuals n, truly excessive and still in increased by employing either the formula of Chandler or the equation (I).

To verify the period of this astronomer, I have made two hypotheses on the value of i, which I have supposed equal to 0°.9 and to 0°.85 by day, corresponding to periods of 398 days and of 423.5 days.[*]

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[*] I have tried the period of 398 days because it agrees perfectly with the values of the angle β, deduced from $u = -\gamma \sin \beta$, $v = \gamma \cos \beta$, which have been determined by me, for 1824.0, from F. W. Struve's RA of Polaris, by Peters for 1842.0, and by Downing for 1872.0 from their observations of latitude.

It may be asked why I have adopted a period of 423.5 days instead of that of Chandler exactly; it is simply for the purpose of having a round number 0.°85 for the facility of calculation. Being obliged to make all these by myself, for want of calculators, I could not neglect any means of abridging a little of the work, already very laborious. And it is for this reason also I have borrowed from the Memoir of Nyrén the co-efficient of the parallax, although it may not be quite equal to that of my term of the systematical aberration.

It would be interesting to begin again these calculations without supposing the longitude of the first meridian to be known; then you should make

$$\nu \sin(2L + \alpha) = \xi$$
$$\nu \cos(2L + \alpha) = \eta$$

It would be very interesting to calculate, by using all the individual observations of Peters', both constants of diurnal nutation, and those of annual and systematic aberration, taking 0''.05 for the parallax.

Truly, you would have 7 unknowns; but the number of observations is great enough to permit of their determination.

By putting $\xi = \nu \sin(2L + \alpha)$, $\eta = \nu \cos(2L + \alpha)$ and calling u the Peters' residuals, the equation of condition will be

$$0 = u \sin \imath t + v \cos \imath t + ax + b'y - \Sigma_1\xi + \Sigma_2\eta + z + (n + b\omega - \tfrac{1}{4} \sin 2\delta \Delta\alpha^2),$$

where $\omega = 0''.05$, and $\Delta\alpha =$ the reduction to the apparent place in RA.

You will assume with Chandler, $i = 0°.843$ per day.

This labor is certainly worthy of trial by an astronomer who has liesure to do it, or assistants to aid him.

I regret that I am not in a position to undertake it myself.

One could reduce it considerably, and obtain nevertheless true results, I think, by adopting for u and v the values I have deduced from Chandler's table of Peters' mean latitudes, which are independent of all errors of reduction, *i. e.*,

$$u = 0''.057, \qquad v = 0''.045.$$

No doubt this computation of the complete series of Peters' observations would give much better results than I have fonnd by only 42 equations, and particularly, I think, a greater value for the constants of systematic aberration and of diurnal nutation, and perhaps, consequently, a negative correction of Struve's constant of aberration.

The application of the equation (I) to the 42 residuals given by Chandler (after the suppression of the two excessive residuals above mentioned) has given, in both hypotheses made upon the period, the new residuals n_1' and n_1''.

The sum Σwn^2 is, if we adopt the residuals of

Peters	2.68
Those of Chandler	1.88
Mine (398 days)	1.58
Mine (423.5 days)	1.43

The only application of the initial or Eulerian nutation gives then a very superior result, especially in the second case, to that of Chandler's formula, which includes an enormous annual term, absolutely empirical, and for me quite inexplicable in theory, unless it be an effect of temperature.

Independently of the terms of the aberration and of the parallax there also exists a small term which the astronomers have neglected in their formulæ and which approaches, in form, that of Chandler; it is the periodical term of systematical aberration; but all these terms are eliminated in the means of the latitudes determined by two (superior and inferior) consecutive transits; at the present I consider the initial nutation only as rendering an accurate account of the residuals thus obtained, and the result is much better than that of Chandler's empirical formula.

Is the geographical action not fixed, by action of physical causes, in the interior of the Earth? That is a question which can be only be ulteriorly resolved by the discussion of numerous and very precise observations made in places differing in longitude by 6, 12 and 18 hours, and reduced by means of absolutely correct formulæ.

§ 3.

In the application of the equation (II), I made naturally an abstract from the two observations above indicated.

n_2 indicates the residuals of Peters, n_2' those which I have deduced from them by reducing them from the terms of the second order and of the parallax.

To these last I have applied the equation (II) which gives me, by the method of Least Squares,

(1st.) Correction of the constant of the aberrations,

$$x = +0''.00095;$$

(2d.) $$y = -0''.035,$$

whence we deduce by taking $K = 20''.4$, since $y = -KK'$ tang δ, for the *reduced* constant of systematical aberration, $K' = 9''$.

(3d.) Constant of the diurnal nutation $\nu = 9''.255$.

The same observations gave to Chandler a positive correction $+ 0''.065$ of the constant of aberration.

Those, much more precise of Nyren, have given him a negative one $- 0''.034$; from these last I myself have obtained $- 0''.037$. It appears to me certain then that the value $20''.40$ is much better than $20''.45$.

The constant $\nu = 0''.255$ that I have deduced from Peters' observations for the coefficient of diurnal nutation is very much too great. Therefore I have taken $\nu = 0''.05, L = 10^h, A' = 280°$, and found

$$x = +0''.048, \qquad y = -0''.025;$$

whence $$K' = 2''.8, \qquad z = 0''.15;$$

what has given the residuals u_2'''.

But Peters' observations are not sufficiently precise to permit of the determination of so small a quantity as the product KK' of both constants of annual and systematical aberration.

All the criteria which may be used are nevertheless verified:

With the *positive* admitted parallax $0''.05$, our calculations give,

A systematical *positive* velocity;

A *positive* constant for the diurnal nutation.

They have led, moreover, to an insignificant correction of the constant of aberration, whilst the very precise observations of Gyldèn have given us a negative one.

A last criterion, in short, of the certainty, I will not say of the numerical results, but of the theoretical expressions of the new terms we have introduced in the formulæ of reduction (diurnal nutation and systematical aberration), is found in the sum of the squares of the residuals multiplied by the weights.

In the observations of Peters mentioned by Chandler

$$\Sigma w n_2^2 = 2.08$$

After having reduced the residuals of Peters from the terms of the second order and of the parallax this sum becomes

$$\Sigma w n_2'^2 = 1.79$$

and for our last residuals n_2'' and n_2''', it is only $\Sigma w n_2''^2 = 1.81$, $\Sigma w n_2'''^2 = 1.30$, whilst for those of Chandler (abstracts being made of the two suppressed observations) it is $\Sigma w v_2^2 = 123$.

§ 4. CONCLUSIONS.

(1.) As to the initial or Eulerian nutation, Chandler's period seems the best; and the simple application of this nutation gives much better results than Chandler's formula of *variation of latitude*.

(2.) As to the diurnal nutation, we can admit of $\nu = 0''.05$ and $L = 10^h$ E. from Pulkova.

(3.) From the parallax of Polaris we can take with certainty $\omega = 0''.05$.

(4.) As to the systematical aberration, we can admit of $A = 280°$; but the systematical velocity wants still a new determination; it is great enough, nevertheless, that we must not neglect the periodical terms of systematical aberration in the reduction of circumpolar stars.

(5.) As to the constant of annual aberration, of which little is yet known, I think the value $20''.4$ approaches more nearly the truth than $20''.45$.

In the following table the two first columns, n_1 and v_1, give the residuals of Peters and Chandler; n_1' and n_1'' my residuals in both hypotheses (period of 398 or 423.5 days); the three columns, n_2, v_2, n_2', n_2'', Peters', Chandler's and my residuals.

t		w	n_1	v_1	n_1'	n_1''	n_2	v_2	n_2'	n_2''
	1842.		″	″	″		″	″		
March	14	4	+.15	+.14	+.176	+.18	+.30	+.27	+.23	+.22
	20	5	+.05	+.06	+.080	+.08	.00	−.04	+.08	+.08
April	3	3	−.20	−.18	−.164	−.17	−.13	−.18	−.21	−.19
	10	3	−.01	.00	+.027	+.01	+.09	+.02	+.01	+.04
	16	5	+.11	+.13	+.147	+.13	+.06	−.01	−.02	+.01
	28	5	+.11	+.13	+.147	+.12	−.05	−.13	−.12	−.03
May	4	3	+.10	+.12	+.132	+.10	+.30	+.22	+.23	+.23
	14	3	+.04	+.06	+.067	+.03	+.18	+.09	+.12	+.14
	24	3	+.05	+.07	+.069	+.03	+.09	+.01	+.05	+.02
	28	3	−.07	−.05	−.054	−.09	+.12	+.04	+.08	+.03
June	6	10	−.07	−.06	−.063	−.09	+.10	+.02	+.07	−.01
	22	8	−.06	−.06	−.071	−.10	+.15	+.07	+.14	−.04
July	6	7	+.02	.00	−.011	−.03	+.06	.00	+.06	−.07
	18	7	−.07	−.09	−.117	−.13	+.06	.00	+.07	−.06
Aug.	6	11	+.05	.00	−.024	−.04	−.02	−.05	+.01	−.11
	19	10	−.01	−.06	−.101	−.10	−.04	−.05	−.03	+.08
	21	6	.00	−.06	−.094	−.10	−.07	−.07	−.06	−.10
Sept.	16	8	+.16	+.08	+.054	+.06	−.05	−.02	−.04	−.01
	24	3	+.15	+.07	+.021	+.04	+.07	+.10	+.08	+.14
Oct.	4	3	+.04	−.05	−.096	−.07	−.06	−.01	−.05	+.04
	14	10	+.15	+.06	+.009	+.04	+.04	+.10	+.04	+.14
	22	3	+.23	+.14	+.087	+.12	−.19	−.12	−.18	−.08
	1843.									
Feb.	1	2	−.05	−.06	−.109	−.07	−.20	−.17	−.23	−.34
	18	5	−.04	−.04	−.075	−.04	−.01	−.01	−.06	+.14
Mar.	7	3	−.04	−.03	−.060	−.04	+.03	+.01	−.03	−.07
	18	6	+.02	+.03	+.021	+.04	−.05	−.09	−.12	+.12
	24	7	−.09	−.08	−.083	−.06	.00	−.04	−.07	+.05

	t.	*w*	n_1	v_1	n_1'	n_1''	n_2	v_2	n_2'	n_2''
	1843.		″	″	″		″	″		
Apr.	3	5	−.04	−.03	−.023	−.01	+.05	−.01	−.02	+.02
	18	8	−.02	−.02	+.008	+.01	+.08	+.01	+.01	+.05
	26	7	+.02	+.02	+.052	+.01	+.03	+.04	−.03	+.00
	29	2	−.09	−.10	−.056	+.06	+.23	+.15	+.17	+.20
Sept.	14	11	+.17	+.05	+.086	+.10	−.03	.00	−.03	+.02
	25	9	+.15	+.03	+.053	+.08	.00	+.04	−.01	+.06
Oct.	6	5	+.21	+.10	+.099	+.12	−.03	+.02	−.04	+.06
	25	4	+.10	+.01	−.029	+.00	−.19	−.08	−.20	−.19
Nov.	18	2	+.44	+.38	+.298	+.03	−.03	+.05	−.04	+.00
	1844.									
Mar.	22	3	+.12	+.20	+.085	+.09	+.01	−.03	−.05	−.03
Apr.	7	7	.00	+.06	−.013	+.02	+.13	+.07	−.06	−.03
	19	6	.00	+.04	+.001	.00	+.04	−.03	−.02	+.03
May	4	6	−.16	−.14	−.144	−.15	+.06	−.02	+.01	+.03
Oct.	10	2	+.01	−.17			−.07	−.01	−.09	+.02
	31	2	−.26	−.41			−.14	−.06	−.17	+.03
	[*wnn*]	[*wvv*]	2.68	1.88	1.58	1.43	2.08	1.23	1.79	1.81

ON A NEW PENDULUM ESCAPEMENT*

The uniformity of movement of our pendulum chronometers depends mainly upon two conditions, viz., upon the accuracy of the escapement and the completeness of the compensation of the pendulum.

In both respects Mr. Sigmund Riefler, engineer and manufacturer at Munich, Germany, after many years of experimenting, has succeeded in constructing pendulum clocks which, according to the practical results recorded in the Munich Royal Observatory and elsewhere, constitute a decided progress in chronometry.

I.

The object of the escapement of this entirely new chronometric system, which also has been employed for watches and tower clocks, is to secure greater accuracy in the movement than is offered by existing escapements.

In this escapement the pendulum swings with perfect freedom, being connected with the clock-work solely through the pendulum spring from which it receives the impulse.

The impulse is communicated by the wheel-work bending the pendulum spring a little at each oscillation of the pendulum, which produces a slight tension in the spring.

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* A paper read before the Congress of Astronomy and Astro-Physics at Chicago by Mr Leman "On a New Pendulum Escapement with perfectly free pendulum, the impulse being communicated in the axis of oscillation and at the moment in which the pendulum swings through the dead point, and a New Mercurial Compensation Pendulum, invented by S. Riefler, engineer and manufacturer at Munich.

This tension-force of the pendulum spring gives the pendulum the impulse. As this bending takes place round an axis which is identical with the axis of oscillation of the pendulum, and further occurs every time almost at the moment in which the pendulum is swinging through the dead point, we gain not only the perfect freedom of the pendulum, but also the great advantage that irregularities in the communication of force from the wheel-work and in the resistances to escape can exert no detrimental influence on the uniformity of the motion of the clock. This is not only in accordance with scientific theory, but has been practically proved by the excellent performance of numerous astronomical, turret and other clocks provided with this escapement.

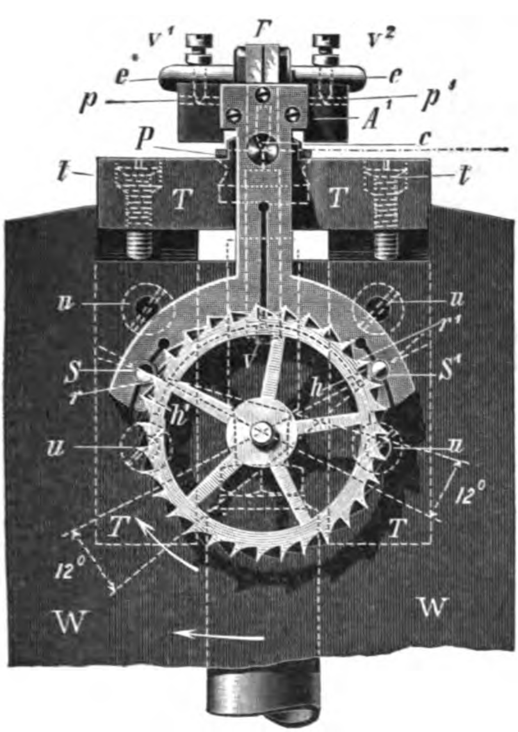


FIG. 1. Scale 5 6.

Fig. 1 of the drawings shows a front view, Fig. 2 a side view of the escapement on a scale of 5/6. Fig. 3 is the view from above in natural size dimensions for astronomical clocks.

Figs. 4 and 5 are illustrations of the suspension of the pendulum in actual size with axle and pendulum spring.

TT is a strong cast metal support fastened by four screws, *uu*, to the back plate *W* of the clock. To this support are fixed the two bearing stones *PP*, the upper surfaces of which lie in a single horizontal plane.

On this plane lies the axle of rotation *aa* of the anchor *A*, the axle being formed by the knife edges of the steel prism *cc*. The axle of the anchor receives the necessary direction for the regular locking of the anchor in the escape wheels *H* and *R* from the conical ends of the screws *KK'*, which, however, are screwed back a little when the pendulum *B* is suspended, in order not to interfere with the free play of the anchor.

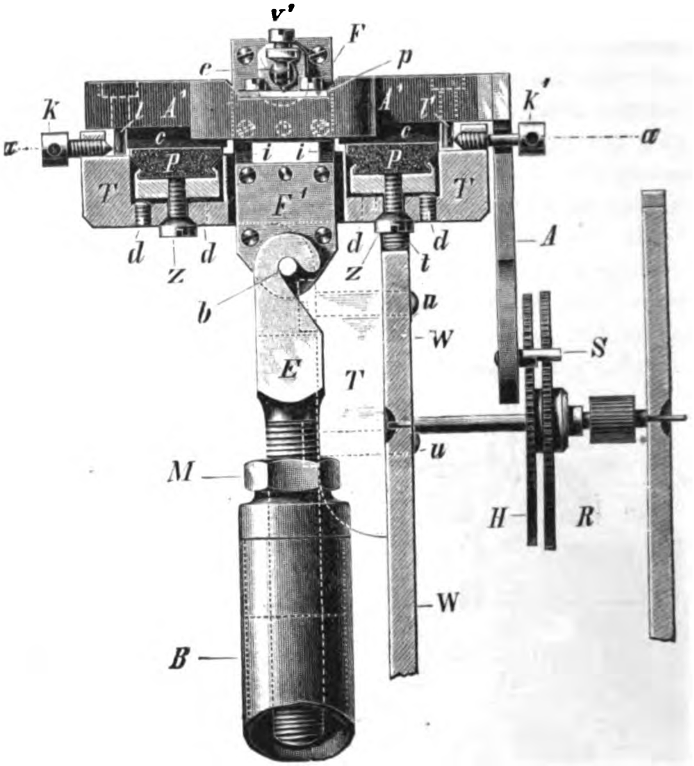


FIG. 2. 5/6 natural size.

FF′ is the suspension of the pendulum placed on the anchor-piece *AA′*, together with the pendulum spring *ii*, the axis of curvature of which is identical with the axle of rotation *aa* of the anchor.

The escape wheel is a double wheel, consisting of the driving wheel *H* and the rather larger locking wheel *R*. The teeth *hh′* of the former with their bevel surfaces effect the driving, the teeth *rr′* of the latter with their radial surfaces effect the locking.

S and *S′* are the driving and at the same time the locking pallets of the anchor. They are cylindrical, and are beveled at their front ends to the centre of the axis of the cylinder.

On the cylinder surface the driving of the anchor is effected by the teeth of the driving wheel *H*, the locking is effected on the plane surfaces by the teeth of the locking wheel *R*.

The play of the escapement is as follows:

Fig. 1 shows the escapement at the moment when the pendulum is at the dead point and the teeth *r* of the locking wheel rests on the plane surface of the pallet *S*.

Now, when the pendulum swings out to the left in the direction of the arrow, the pendulum spring *ii* at first remains quite straight and the beginning of the oscillation takes place round the knife edge axle *aa* of the anchor. The anchor *A* being connected with the pendulum by the pendulum spring *ii*, will share this oscillation of the pendulum until the point of the teeth *r* of the locking wheel falls from the locking surface of the pallet *S*. Up to this point the pendulum has described an arc of about ¼°. By this time the cylindrical surface of the pallet *S'* has approached the driving tooth *h* of the driving wheel as far as is necessary for play, the wheels revolve in the direction of the arrows until the locking tooth *r'* lies on the plane surface of the pallet *S'*, and during this revolution the driving tooth *h* effects the driving: *i. e.*, it forces the pallet *S'* back and thus moves the anchor in an opposite direction to that in which the pendulum oscillates.

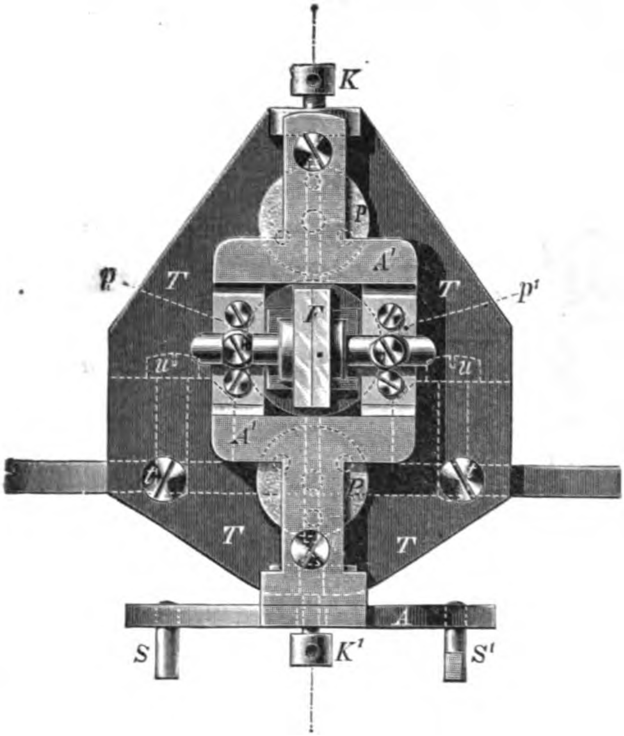


FIG. 3. Natural size.

By means of this revolving motion of the anchor effected by the wheel-work the pendulum spring *ii* is slightly bent round the axis of oscillation *aa* and thus receives a slight tension which imparts the impulse to the pendulum. The pendulum, however, does not immediately yield to the impelling force, but first completes its oscillation to the left, the anchor remaining the while at rest. This complementary arc amounts to 1¼° in the astronomical clocks, and to 2½° in large turret clocks.

As the pendulum returns and after it has passed the dead-point towards the right, the tooth r' which had been resting upon S' becomes free and a new impulse takes place on the other side by means of the tooth h'.

The illustrations also show several small parts of the construction which have hitherto not been mentioned. Strictly speaking they have nothing to do with the working of the escapement, but are simply regulative appliances for its correct and convenient attachment.

The conical screw v (Fig. 1) serves to regulate the breadth of the anchor, while the depth to which the anchor locks into the escape wheels is regulated by the screws tt.

Suspension of Pendulum.

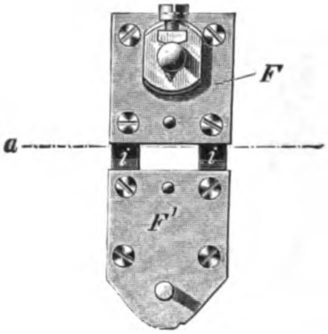


FIG. 4.

Natural Size.

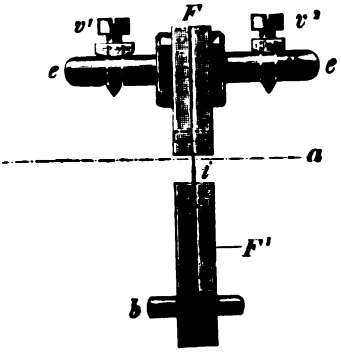


FIG. 5.

The screws $v^1 v^2$ of the pendulum suspension, which may be kept in position by small nuts, regulate the height of suspension of the pendulum in such a way that the axis of curvature of the pendulum spring *ii* always coincides with the knife-edge axle, being the axis of rotation *aa* of the anchor. At the same time this screw regulates the regular fall of the pendulum.

The conical surfaces of the bearing screws $v^1 v^2$ of the pendulum suspension do not rest directly on the anchor-piece $A'A'$, but on thin washer-plates pp', provided with corresponding hollows and screwed onto the anchor-piece $A'A'$, but still allowing a little play in the screw-holes. In this way the knife-edge axle *aa* may be made to coincide accurately in a horizontal direction with the axis of curvature of the pendulum spring.

I and I' are screwed-in steel pins with conical hollows at the sides, which fit the conical points of the directive screws KK'.

The bearing stones PP rest each with its brass frame on three pressure screws, the thread of which is in the pendulum support *T*. By means of these screws the stones are brought to the required height, and also so adjusted that their plane surfaces form a common plane. The set screws *Z* keep them in the required position.

It will be easily perceived that the resistances which operate on the pendulum in consequence of its connection with the clock-work consist solely in the friction of the axle of the anchor and in the resistance of discharge which arises when the teeth of the locking wheel glide down from the locking surface of the pallets. Both these resistances are extremely trifling, and, in addition to this, of very constant magnitude.

The friction of the axle of the anchor consists simply of the imperceptibly small rolling friction of the steel knife-edges *cc* on the perfectly plane and very hard bearing stones *PP*. Moreover this friction influences the pendulum only for a brief moment when the pendulum is swinging through the dead point, that is to say in that portion of the oscillation, amounting to only ½°, in which the pendulum moves with the greatest speed. During much the greater part of the arc of oscillation the pendulum swings round the axis of the pendulum spring.

The resistance of discharge on the stone pallets *S* and *S'* is also almost zero, because the locking planes are not placed radially but form an angle of about 10°-12° with the radius of the escape wheels, which is equivalent to the angle of friction between stone and brass. The pallets are adjusted to slide, and not to draw as is the case with the anchors of watches.

The danger of a premature discharge is excluded, because the pallets are pressed onto the teeth of the driving wheel by the tension which the pendulum spring undergoes when the pendulum swings out.

The principal advantages of this new escapement (Germ. Imp. Pat. No. 50739) are as follows:

1. The pendulum swings with perfect freedom and without being influenced by the clock-work.

2. The impulse is communicated to the pendulum in the axis of oscillation; and the impelling lever has consequently the least possible length. The length is merely a fraction of a millimetre, since the curvature of the pendulum spring only extends over such a small space.

3. Irregularities in the transmission of force and in the resistances of discharge exert no disturbing influence on the regularity of the motion of the clock.

4. The supplementary arc of the the escapement is in astronomical clocks 3 to 5 times, and in church clocks 8 to 10 times, as great as the arc of discharge.

The pendulum is therefore to a high degree non-sensitive to disturbing influences of a mechanical character.

5. The number of working parts in this escapement is smaller than in any other known escapement. It consequently works with the greatest exactness.

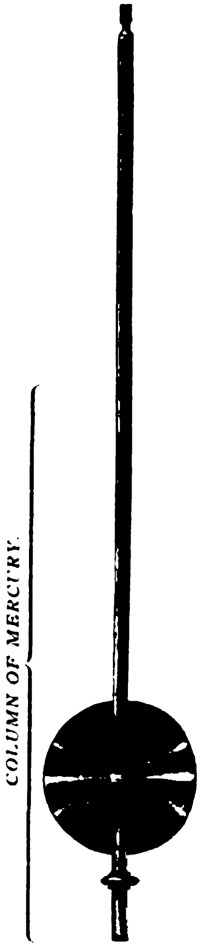
II.

Of the different compensation-pendulums hitherto employed the mercurial compensation-pendulum invented in 1721 by the Englishman Graham enjoys the best reputation, for which reason it has beeen used in nearly all astronomical and other pendulum clocks of precision.

But even this pendulum has great defects, which are: (1) incorrect functioning when the temperature of the air differs at different levels, and (2) sensitiveness to sudden changes of temperature. Besides, the shape of this pendulum prevents it from cutting the air easily, and consequently changes in the atmospheric pressure (height of barometer) exercise a comparatively strong influence on the running of a clock having such a pendulum.

These defects are almost entirely obviated by the mecurial compensation-pendulum of Riefler (Germ. Imp. Pat. No. 60059) shown in the cut, which illustrates a second's pendulum one-tenth of the actual size.

It consists of a Mannesmann steel tube (rod), bore 16 mm., thickness of metal 1 mm. filled with mercury to about two-thirds of its length. The pndulum has, further, a metal bob weighing several kilograms and shaped to cut the air; below the bob are diec-shaped weights attached by screw-threads for correcting the compensation, the number of which may be increased or diminished as appears necessary.



Whereas in the Graham pendulum correction is effected by altering the height of the column of mercury, in this pendulum it is effected by changing the weight of the pendulum and thus the height of the column of mercury always remains the same.

A correction of the compensation should be effected, however, only in case the pendulum is to show sidereal time, instead of mean solar time, for which latter it is calculated. In this case a weight of 110 to 120 grams should be screwed on to correct the compensation.

In order to calculate the effect of the compensation it is necessary to know precisely the co-efficients of the expansion by heat of the steel rod, the mercury, and the material of which the bob is made.

The last two of these co-efficients of expansion are of subordinate importance, the two adjusting screws for shifting the bob up and down being fixed in the middle of the latter. A slight deviation is therefore of no consequence. In the calculation for all these pendulums the co-efficient for the bob is therefore fixed at 0.000018 and for the mercury at 0.00018136, being the closest approximation hitherto found for chemically pure mercury such as that used in these pendulums.

The co-efficient of expansion of the steel rod is, however, of greater importance. It is therefore ascertained for every pendulum constructed in Mr. Riefler's factory by the *physikalisch-technische Reichsanstalt* at Charlottenburg, under the surveillance of the author of this paper, his examinations showing, in the case of a large number of similar steel rods, that the co-efficient of expansion lies between 0.00001034 and 0.00001162.

The precision with which the measurements are carried out is so great that the error in compensation resulting from a possible deviation from the true value of the co-efficient of expansion as ascertained by the Reichsanstalt, does not amount to over ± 0.0017; and, as the precision with which the compensation for each pendulum may be calculated absolutely precludes any error of consequence, Mr. Riefler is in a position to guarantee *that the probable error of compensation in these pendulums will not exceed ± 0.005 second per diem and ± 1° variation in temperature.*

A subsequent correction of the compensation is therefore superfluous, whereas with all other pendulums it is necessary, partly because the co-efficients of expansion of the materials used are arbitrarily assumed; and partly because none of the formulæ hitherto employed for calculating the compensation can yield an exact result, for the reason that they neglect to notice certain important influences, in particular that of the weight of the several parts of the pendulum. Such formulæ are based on the assumption that this problem can be solved by simple geometrical calcution, whereas its exact solution can be arrived at only with the aid of physics.

This is hardly the proper place for details concerning the lengthy and rather complicated calculations required by the method employed. It is intended to publish them later, either in some mathematical journal or in a separate pamphlet. Here I will only say that the object of the whole calculation is to find the allowable or requisite weight of the bob, *i. e.*, the weight proportionate to the co-efficients of expansion of the steel rod, dimensions and weight of the rod and the column of mercury being given in each separate case. To this end the relations of all the parts of the pendulum, both in regard to statics and inertia, have to be ascertained, and for various temperatures.

A considerable number of these pendulums have already been constructed, some of which have been running for more than a year. The precision of this compensation which was discovered by purely theoretical computations, has been thoroughly established by the ascertained records of their running at different temperatures.

The adjustment of the pendulums, which is, of course, almost wholly without influence on the compensation, can be effected in three different ways:

(1). The rough adjustment by screwing the bob up or down.

(2). A finer adjustment by screwing the correction discs up or down.

(3). The finest adjustment, by putting on additional weights.

These weights are to be placed on a cup attached to a special part of the rod of the pendulum. Their shape and size is such that they can be readily put on or taken off while the pendulum is swinging. Their weight bears a fixed proportion to the static momentum of the pendulum, so that each additional weight imparts to the pendulum, for twenty-four hours an acceleration expressed in even seconds and parts of seconds, and marked on each weight.

Each pendulum is accompanied with additional weights of German silver for a daily acceleration of 1 sec. each, and ditto of aluminum for an acceleration of 0.5 and 0.1 second respectively.

A metal clasp attached on the rear side of the clock-case, may be pushed up to hold the pendulum in such a way that it can receive no twisting motion during adjustment.

Further, a pointer is attached to the lower end of the pendulum, for reading off the arc of oscillation.

The essential advantages of this pendulum over the former mercurial compensation-pendulums are the following:

(1). It follows the changes of temperature more rapidly, because a small amount of mercury is divided over a greater length of pendulum, whereas in the older ones the entire (and decidedly larger) mass of mercury is situated in a vessel at the lower end of the pendulum-rod.

(2). For this reason differences in the temperature of the air at different levels have no such disturbing influence on this pendulum as on the others.

(3). This pendulum is not so strongly influenced as the others by changes in the atmospheric pressure, because the principal mass of the pendulum has the shape of a lens, and therefore cuts the air easily.

(4). *These pendulums are delivered with the compensation fully adjusted, thus avoiding all correction of the compensation,* such as is necessary with all other compensation pendulums, and which can be arrived at only after tedious experiments.

RESULTS OF PRACTICAL TESTS OF THE PENDULUM.

It was mentioned in the description of this pendulum that the accurate working of this compensation, deduced from theoretical principles, had been confirmed by the practical results. The proof of this may be found in the following extract from the table of rates registered by the Royal Observatory at Munich.

The table refers to the first pendulum of this kind, marked No. 1, which on its completion at the end of July, 1891, was to be submitted to this test, and for this purpose was hung in one of the astronomical clocks belonging to the Observatory at Munich.

This clock possesses a perfectly free escapement, German patent No. 50,739, as described above and also in numerous German and foreign technical journals as well as in Meyer's Konversations-Lexicon, Annual supplement 1890-1891, pp. 945-947. For nine months previously the clock had gone with a mercurial compensating pendulum of the hitherto usual construction; but it was not until the new pendulum was inserted that its rate attained that high degree of uniformity which corresponds to the perfection of the escapement used.

The clock stands in a room which is immediately connected with the great meridian hall of the Observatory. It is therefore subject to sudden variations of temperature of considerable degree, as the cold night air penetrates into the clock-room every time an observation is made, and the temperature consequently sinks rapidly. The observations for time were made on every clear day by Mr. List, an assistant in the Observatory, with Reichenbach's meridian instrument. They include, as a rule, the meridian transits of several stars as well as of one or more polar stars. The days in question are given in the first column of the table. The daily rates (col. 2) indicate a certain dependence on atmospheric pressure (col. 5). The clock generally goes a little slower when the barometer is high than when it is low. The last column, therefore, contains the rates reduced to a uniform atmospheric pressure so that they may be compared directly with each other.

To reduce the mean daily rate of each series of observations (col. 3) to the mean barometric pressure of Munich 715.83 mm. (last col.), the influence of the barometer on the pendulum has been taken as 0.01 second daily for 1 mm. of alteration in the atmospheric pressure.

To enable a judgment to be formed as to the compensation for heat of this pendulum, this table contains, deduced from a long period of running, the daily rates in three series of rates during extremes of temperature.

It thus appears that the rate of the clock, from September, 1891, to December, 1891, with a maximum variation of temperature of 27° C. only varied by 9 thousandths of a second; and from December, 1891, to August, 1892, with a maximum variation of temperature of 31°, only by 2 thousandths of a second.

The error of compensation for ±1° C., therefore, amounts to only 0.0005 and 0.0001 of a second respectively. A correction of the compensation has not taken place, but the proportions of the weight and dimensions of the pendulum have remained the same as were fixed by calculation. It is to be observed that the daily fluctuation of temperature, to which the pendulum is exposed, is about 3° C.

As a verification of the foregoing data and as a testimony to the results, the following certificate from the Director of the Munish Observatory, Professor Dr. Seeliger, may be quoted here:

"From the following table of rates, extracted from the records of this Observatory, it appears that with a variation of temperature up to 30° C., no influence worth mentioning on the rate of the clock can be perceived. It is therefore probable that the new pendulum answers all requirements in as high a degree as is ever likely to be attained. A similar perfection has only exceptionally

ROYAL OBSERVATORY, MUNICH,

EXTRACT FROM THE REGISTERED TABLE OF RATES OF RIEFLER'S ASTRONOMICAL CLOCK, NO. 1

With Riefler's Perfectly Free Escapement, German Patent No. 50,739, and Riefler's Mercurial Compensation Pendulum, German Patent No. 60,059.

Date of Comparison of Time.	Observed Daily Rate. Seconds.	Mean Daily Rate of the Observed Series. Seconds.	Temperature. C. deg.	Mean of Barometer.		Rate Reduced to 715.83 mm. barometer seconds.
				Between Two Observations. mm.	Of the Entire Series. mm.	
1891 Sept. 1.....			+ 19.4			
	− 0.06			715.5		
" 2.....			+ 20.6			
	− 0.07			717.5		
" 3.....			+ 21.3			
	+ 0.06			717.8		
" 7.....			+ 18.6			
	+ 0.08	+ 0.030		719.75	719.03	− 0.002
" 9.....			+ 18.6			
	+ 0.02			722.8		
" 10.....			+ 18.1			
	+ 0.09			722.1		
" 11.....			+ 18.6			
	− 0.05			720.7		
" 12.....			+ 18.6			
1891 Dec. 5.....			+ 5.6			
	+ 0.04			718.52		
" 10.....			+ 5.0			
	+ 0.02			712.50		
" 12.....			+ 5.0			
	+ 0.11			719.16		
" 21.....			− 1.9			
	+ 0.06	+ 0.023		721.94	717.45	+ 0.007
" 23.....			− 3.8 − 5.7			
	+ 0.07			729.15		
" 28.....			− 1.0			
	− 0.02			715.80		
" 31.....			+ 4.0			
	− 0.08			710.12		
1892 Jan. 10.....			± 0.0			
1892 Aug. 16.....			+ 22.3			
	+ 0.02			720.6		
" 18.....			+ 23.8			
	− 0.01			715.3		
" 19.....			+ 25.3			
	0. 0 5			711.9		
" 20.....			+ 24.4			
	+ 0.05	+ 0.010		718.05	716.33	+ 0.005
" 22.....			+ 24.4			
	+ 0.03			715.02		
" 27.....			+ 21.3			
	− 0.01			715.52		
Sept. 1.....			+ 20.6			
	+ 0.06			720.40		
" 2.....			+ 20.6			

been attained by the ordinary compensations and even then only after long series of experiments and, strictly speaking, only by accident, while the distinguished success of this pendulum is based on calculations which may be made in advance with almost absolute accuracy. I therefore feel convinced that this new pendulum of Mr. Riefler's is a most important and welcome progress.

[Signed] H. SEELIGER,
Director of the Royal Observatory.
Royal Observatory, Munich, 3 Nov., 1892."

COMPARISON OF THE CONSTANTS OF COMPENSATION OF SOME OF THE BEST ASTRONOMICAL CLOCKS.

This table includes all clocks the rates of which have been published and were accessible to Mr. Riefler.

The last column contains references to the authorities from which the figures are taken.

No.	Name of clock and its location.	Daily variation of rate for + 1° C. sec.	Greatest difference of temp. C°	Authorities.
1	Hohwü Nr. 17	— 0.0151	17.6	Kaiser, Astr. N, vol. 63, Nr. 1502.
2	Tiede Nr. 400 Observatory Berlin....	+ 0.0222	15.4	Zwink, Inaug. Dissert. 1888.
3	Knoblich Nr. 1952 Observatory Potsdam	— 0.0360	16.8	Becker, Astr. N. Vol. 96, Nr. 2290.
4	Dent, Obs'y Hongkong.	+ 0.0350	......	Doberck, Astr. N. Vol. 120, Nr. 2868.
5	Hohwü Nr. 34 Observatory Upsala..	— 0.0350 — 0.0265	15	Schultz, Astr. N. Vol. 103, Nr. 2452.
6	Knoblich Nr. 1847........	— 0.0025	19	Schumacher, Astr. N. Vol. 91, Nr. 2166.
7	Dencker Nr. 12 Observatory Leipzig..	—0.0160	22	R. Schumann, Ber. d. k. s. Gesellsch. d. Wiss. 1888.
8	Hipp, Observatory Neuchâtel (1885-1887).	+ 0.0610	......	Hirsch, rapport general sur l'observ. de Neuchatel.
	Ditto (1888-1890)........	— 0.0049	16.5	
9	Knoblich Nr. 1770 Observ. Bethkamp.....	— 0.0442	19.8	Tetens. Inaug. Dissert. 1892.
10	Riefler Nr. 1. Observ. Munich.........	+ 0.0008	31	Anding, Observatory Munich.

The last value was determined at the Munich Observatory by Dr. Anding from four weekly rates taken from a period covering an entire year. The value lies within the amount of the mean error. The entire results of the calculation in question will be published in the *Astronomische Nachrichten.*

The difference in the two constants of compensation of the pendulum of Hipp, Neuchatel, is due to the correction of computation effected on this pendulum. Its quantity of mercury was increased by 53 gr. on February 25th, 1885, and by 570 gr. on June 7th, 1888.

As shown by this comparison, Riefler's pendulum No. 1 possesses a constant of compensation which is considerably smaller than that of any of the other pendulums compared. Riefler's pendulum has therefore stood the test of compensation brilliantly. This may be taken as a proof of the great exactitude with which the co-efficients of expansion of the Mannesmann steel tubes used for this pendulum were determined by the Imperial Physio-technical Institute, and also of the accuracy of the calculation of compensation.

As far as at present ascertained, equally favorable results have been attained with the other 27 pendulums hitherto constructed by Mr. Riefler.

THE SO-CALLED LAW OF BODE AS APPLIED BY CHALLIS TO SATELLITES.

W. T. Lynn in *Observatory* for October, gives an interesting note "On the Extension of Bode's Empirical Law of Distances of the Planets from the Sun and of Satellites from their Primaries" as applied by Challis, who drew the curious inference that there can be no planet nearer the Sun than Mercury, and no satellite nearer the several primaries than the nearest of those in each system already discovered. Mr. Lynn remarks that the last part of the inference reads oddly now in view of Professor Barnard's discovery in the system of Jupiter.

The addition of Hyperion to the system of Saturn in 1848 made it necessary for Professor Challis to introduce into the formula of the so-called law an extra term.

For Uranus, Challis obtained conformity with a series of the same form as that for Jupiter* (a, $a + b$, $a + rb$, $a + r^2b$), adding two more terms of the form $a + r^3b$, $a + r^4b$. But this is by accepting the whole of the six satellites announced by Herschel, four of which have long since ceased to be regarded as real. Challis remarks that their existence had been doubted, but thinks that the conformity of their distances to this law confirms their reality, though they were probably smaller than the two which were undoubted. The so-called law, however, cannot apparently be fitted in any shape to the distances of the four satellites which are now known and probably form the whole system. These distances are approximately in the proportion 4, 5½, 9, 12, or 3, 4, 7, 9.

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* Numerically for Jupiter, 7, 7 + 4, 7 + 4 × 2½, 7 + 4 × $(2½)^2$, or 7, 11, 17, 32.

Astro-Physics.

ON THE NEW STAR IN AURIGA.*

H. C. VOGEL.

The news that a new star had been discovered in the Constellation Auriga, in the last days of January, 1892, reached me on the 2d of February, and soon thereafter came the further information that the spectrum of the star contained numerous bright lines and offered much that was of the greatest interest.

As the star was of only the 5th magnitude, it was evident that the employment of the large spectrograph which I have used for motions of stars down to the third magnitude, was out of the question; it was therefore a particularly fortunate circumstance that in January, 1892, I had constructed a spectrograph with small dispersion, which could be connected with the photographic telescope.

On account of unfavorable weather, it was unfortunately not possible to observe the new star until February 14th. Investigation with a small eyepiece spectroscope, and with a larger compound spectroscope on the 11-inch refractor, showed that the spectrum of Nova Aurigæ was remarkably like that of Nova Cygni (1876) when the latter star first appeared, and a sketch which I made agreed very exactly with the first figure in the plate which accompanies my memoir on the new star in the Swan, printed in the *Monatsberichte* of the Academy for May, 1877. The continuous spectrum was very strong and it could be traced for a surprising distance toward the violet end; it was crossed by many very broad and for the most part very bright lines, among which the hydrogen lines C and F, and three lines in the green, were particularly conspicuous. A number of broad dark bands were also recognized, but it could not be determined with certainty whether they were real, or only the result of the absence of bright lines at certain places in the spectrum. Although the spectrum was of great interest on account of this abundance of bright lines, its aspect was nevertheless not an unexpected one, for most new stars which have been observed since the introduction of spectrum analysis into astronomy have given spectra with bright lines.

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* Translated from the *Abhandlungen der konigl. preuss. Akademie der Wissenschaften*, Berlin, 1893. The geographical miles in the original have been reduced to English statute miles; 1 geo. mile = 4.61 statute miles.

The result obtained by photographing the spectrum was, however, quite surprising. The spectrum extended far into the violet, and showed at the same time many bright and broad lines, among which the whole range of hydrogen lines, from F to the rythmically-ordered lines in the violet, were especially noticeable; but on the more refrangible side of most of these were broad dark lines, whose distances from the bright lines increased in going toward the violet, in proportion to the increasing dispersion of the prism, and whose identity with the bright lines was thereby established. It was at once evident that the spectrum was not that of a single body, but was made up of the superposed and relatively displaced spectra of at least two bodies, which, as shown by the displacement, were moving with great relative velocity. Several of the dark lines were afterwards recognized in visual observations, closely adjacent to the sides of the corresponding bright lines.

It cannot be said, in this connection, that the discovery of the double spectrum of the Nova is alone due to the application of photography, for with the powerful instruments of the present time the spectrum of a fifth magnitude star is bright enough, even with high dispersion, to allow the detection of the dark lines near the bright ones, and it may also be assumed that, even with instruments of moderate size the general character of the Nova's spectrum would have been correctly ascertained. The superiority of the photographic method as compared with direct observation appears most clearly and undubitably in detailed observations and measurements, which in the case of a fifth magnitude star are only in a very restricted degree possible with an instrument of small dimensions, while spectrograms taken with the same instrument allow really accurate measurement, and are capable of furnishing material for important conclusions. For this reason the detailed observation of the spectrum of such an interesting object as the Nova is not limited to instruments of the greatest dimensions.

In what follows I have given in section I the spectroscopic observations which have been made here: in section II, I have given an abstract of the most important observations of others which are so far known, particularly those which relate to the spectrum of the Nova; and, finally, in section III, the conclusions which have been drawn from the observations, together with my own views in regard to the Nova.

I. OBSERVATIONS AT POTSDAM.

The Visible Spectrum.

On Feb. 14, 1892, direct observations were made with a spectroscope of medium size provided with a slit, and with an eye-piece spectroscope, in connection with the 11-inch refractor; on the succeeding days with the eye-piece spectroscope only. The impression made by the spectrum has been described in the introductory sentences. No changes could be perceived in the first days of observation.

More detailed investigations were made on the 20th of February with the larger spectroscope above mentioned, likewise in connection with the 11-inch refractor. The dispersion of the apparatus was sufficient to allow the nickel line to be seen between the D lines in the solar spectrum. The hydrogen lines C, F, and Hγ were bright in the spectrum of the Nova, and were identified with entire certainty by means of a hydrogen spectrum tube placed in front of the slit. These lines were broad in the star spectrum, and they were perceptibly brighter and more sharply defined on the side toward the violet than on that toward the red. This appearance was especially noticeable in the case of the Hγ line. The lines were three or four times broader than the lines of the comparison spectrum; relatively to the latter they were displaced strongly toward the red, in such wise that the center of each lay outside the comparison line, which coincided with upper third of the broad line in the star spectrum. On account of the comparatively high dispersion the continuous spectrum was weak, and only the broad dark F line could be recognized with certainty, adjoining the bright line on its more refrangible side and about equal to it in breadth. The dark line was therefore completely separated from the artificial hydrogen line, and strongly displaced toward the violet.

Between C and F a great number of bright lines could be recognized, but most of them were too faint for measurement. Two of the brighter lines fell very nearly at the places of the principal nebular lines, and I therefore took some pains to determine their wave-lengths as exactly as possible. Mr. Frost, now Director of the Dartmouth College Observatory, New Hampshire, who at this time was in Potsdam, assisted me in these observations. By comparison with the lines given by a hydrogen tube, the wave-length 492.5$\mu\mu$ was found for the weaker of the two lines, which was broad and ill-defined on the sides, and the wave-length 501.6$\mu\mu$ for the brighter line. These determinations may be considered as accurate within the limits of about ± 0.3$\mu\mu$, and hence it appears without doubt from the observations that the brighter line cannot be identified either with the double line of the air spectrum or with the brightest line in the spectrum of the nebulæ; it is even less possible to identify the weaker line with the second line in the nebular spectrum. On the other hand, it appears from Young's catalogue of chromospheric lines that both of the lines in question coincide with lines which are bright and of frequent occurrence in the Sun's chromosphere.

Mr. Frost and I further observed a very broad and bright line in the vicinity of the well-known magnesium group *b*, but it was not possible to determine with certainty whether the lines were to be regarded as identical. The center of the star-line coincided with the sharp edge of the brightest hydro-carbon fluting, and therefore nearly with b_{4}, but on the assumption that the magnesium lines would be displaced toward the red as much as the hydrogen lines, it should have been less refrangible. There is no indication that the star-line was related in any way to the hydro-carbon fluting above mentioned.

A quite bright line in the spectrum of the Nova was in all probability the line λ 531.7 always present in the spectrum of the chromosphere (the corona line). Between *b* (?) and this line two faint lines could be made out,—λ 523 and λ 528$\mu\mu$. The D lines could be identified in the star spectrum with entire certainty and their displacement relatively to the comparison spectrum was distinctly perceptible.

1892, March 2. With an eyepiece spectroscope the lines C, D, several bright lines in the green, F and Hγ were recognized in the spectrum of the Nova. A broad dark band, more refrangible than C, was visible; also broad dark bands between the lines near F.

1892, March 4. Further observations were made with the eyepiece spectroscope. Dr. Wilsing and Dr. Scheiner took part in the observations. Twelve bright lines were seen in the spectrum. C was surprisingly bright and stood quite isolated, as the red of the continuous spectrum faded before reaching it. An isolated line was also seen below C at a distance from it of ½(D − C), probably the chromosphere line λ 705$\mu\mu$. D was quite weak.

1892, March 16. With the eyepiece spectroscope and cylindrical lens a faint continuous spectrum was seen in the yellow and green. F was the brightest line; in addition four or five bright lines in the green were seen, and a very faint line above F, in the violet (Hγ?). D and C were no longer recognizable (Scheiner).

Without the cylindrical lens the continuous spectrum was visible from blue to red, but it was very faint. C and D could be seen as small points of light. The magnitude of the star was 8.5.

1892, March 19. The continuous spectrum is very faint, and falls off very rapidly beyond F, so that it can only be traced as far as Hγ with difficulty. Hγ is still recognizable. F is very distinctly visible, and the brightest line in the spectrum. Several lines (four or five) occasionally glimpsed in the green. C was seen by Scheiner, but not by me. The star was somewhat fainter than the 9th magnitude, its color reddish.

After its second appearance the Nova was first observed on the 17th of September, 1892, by Dr. Scheiner and Dr. Wilsing. The spectrum consisted essentially of a bright line in the green, and an extremely faint continuous spectrum. In the spectroscope without a cylindrical lens the Nova appeared unchanged as a star. A more precise determination of the position of this line in the spectrum was not possible on this evening, or on the following one, when no change in the spectrum could be perceived. In the winter the weather was so unfavorable that an observation was not possible until the 12th of March, 1893. With an eyepiece spectroscope without cylindrical lens on the 9-inch guiding telescope of the photographic refractor, the star was then perfectly unchanged. With the small spectrograph mounted on the photographic refractor (13 inches aperture) I could distinctly perceive three lines whose relative distances corresponded closely with those of the brightest lines in the spectrum of the nebulæ; besides these lines a very faint continuous spectrum was visible in their neighborhood. Taking 10 for the intensity of the brightest line in the green near λ 500, that of the second line (toward the violet from the first) would be 3 or 4, and that of the third, 1.

On account of the faintness of the object, a more accurate determination of the positions of the lines was impossible with the means at our disposal, and I therefore did not attempt it.

The Photographic Spectrum.

The apparatus used for the photographic observations has a 60° prism of very nearly colorless flint glass The dispersion from D to *h* is 4°.0. With the ordinary sensitive plates of Dr. Schleussner, the photographed spectra are about 12 mm. long from λ 490 to λ 372. The great advantage of the photographic refractor on which the apparatus was mounted, in that it unites almost in a point the photographically active rays, is shown very clearly by the fact that the spectrum is linear throughout almost its entire extent. The spectroscope, mounted on a strong circular iron plate with projecting rim, is easily mounted on the telescope in the same way as the metal camera used for direct photographs, and by means of the draw-tube, which also serves for focusing the plates, the slit can be placed very exactly in the focus of rays having a wave-length of $420\mu\mu$. The prism is set to minimum deviation for the same rays. From λ 450 to λ 390 the spectrum is then almost equally sharp.

The photographs were measured with the same microscope which I had used in measuring the photographs taken for the purpose of determining the motions of stars in the line of sight, and which I have described more completely in the Publications of the Astrophysical Observatory.* The pitch of the micrometer screw is ¼ mm.

Since even after the first few photographs it was clear that in the spectrum of the Nova we had to deal not only with the spectra of two bodies, but possibly with the superposed spectra of several, it was not to be expected that essential information in regard to the nature of the Nova,—always the aim of the whole investigation,—could be obtained everywhere throughout the spectrum, even by the most detailed measurements; for there was no possibility of a certain identification of the lines, partly in consequence of their great breadth in the spectrum of the Nova, and partly because the chromospheric lines which are, immediately concerned in the identification, occur mostly in groups, while the broad, bright lines of the star admit of resolution in only a few cases. On this account I have confined myself to a special investigation of the hydrogen lines and the K line, since there could be no doubt in regard to their identity, and since they had moreover a special interest. It is, for instance, evident, under the microscope, that these lines, where they appear as bright lines in the star spectrum, have several maxima of brightness, and that in a second spectrum fine bright lines exist, near the middle of the dark lines which adjoin the bright lines on their more refrangible sides.

The measurements which follow relate exclusively to these lines and the above-mentioned maxima of intensity. Since it was impossible to photograph the spectrum of hydrogen at the same same time and on the same plate with the star spectrum, the spectrum of α or β Aurigæ was photographed by a subsequent exposure so as to nearly touch the spectrum of the Nova on both sides. It was first ascertained experimentally, by photographing on the same plate the spectra of widely separated stars, that the

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* Publ. d. Astroph. Observ. No. 25, S. 31.

stability of the apparatus was great enough to ensure accurate comparisons and reliable measurements by the application of this method. In all except the first two photographs the slit was extremely narrow, and photographs incidentally made of α Tauri or of the Moon, with unchanged slit width, show the spectral lines with extraordinary sharpness and fineness. The exposures were mostly made by Mr. Frost and Dr. Wilsing.

In the following observations the measurements are given in revolutions of the micrometer; the change of wave-length corresponding to one revolution was found by a graphical process to be as follows:

At K	1 rev. = 2.10$\mu\mu$
H	1 rev. = 2.18 "
Hδ	1 rev. = 2.55 "
Hγ	1 rev. = 3.25 "

Plate No. 1. 1892, Feb. 14, 7^h 26^m to 8^h 21^m Potsdam Mean Time.

Plate over-exposed, on account of which the ends of the spectrum, where the photographic action is comparatively weak, are very full of detail. A second spectrum on the same plate, with about 3 minutes exposure, is more suitable for measurement in the middle of the spectrum, although beyond K in the violet it is quite faint.

REGION OF H AND K.

Microm. rev. r		Remarks.
0.63 1.07		Broad dark line, very diffuse.
1.88		Dark line.
2.52 2.56		Dark line with diffuse edges.
2.68 2.92		Fairly bright place in spectrum, perhaps a broad line.
2.92		Very broad, dark line.
3.28	Weak, bright line in the dark line.	
3.60		

Microm. rev. r		Remarks.
3.60		Broad bright band, diffuse toward the red.
3.69 3.85	maxima.	
4.00		
4.60		Very broad dark line.
4.95	Weak bright line inside the dark band.	
5.20		
5.20		Broad bright band, diffuse toward the red.
5.30 5.52	max.	
5.75		

REGION OF Hδ.

Microm. rev. r		Remarks.
0.20		Broad dark band.
0.55	Bright line within the dark band.	
0.79		
0.79		Broad bright band less sharply bounded toward the red.
0.90 1.15	maxima.	
1.36		

REGION OF Hγ.

Microm. rev. r		Remarks.
0.40		Broad dark band.
0.60	Bright line within the dark band.	
0.80		
0 80		Broad bright band somewhat less sharply bounded toward red.
0.90 1 16	maxima	
1.42		

Plate No. 2. 1892, Feb. 15, 7^h 39^m to 8^h 13^m Potsdam Mean Time.

This plate is likewise so much over-exposed that precise measurements cannot be made in the region of Hδ and Hγ.

REGION OF H AND K.

Microm. rev. r	Remarks.
0.66	Broad dark line, very diffuse.
1.00	
1.00	Weak bright line.
1.29	Broad bright line.
1.76	
1.93	Bright line.
2.25	Broad, bright line, stronger than the last, perhaps 2 lines.
2.5	Dark line?
2.63	Broad bright line.
2.85	

Microm. rev. r		Remarks.
2.92		Broad dark line.
3.30	bright line	
3.55		
3.55		Broad dark line.
3.65	maxima	
3.80		
4.03		
4.57		Broad dark line.
4.88	Bright line	
5.08		
5.08		Broad bright line.
5.25	maxima	
5.55		
5.95		

Plate No. 3. 1892, Feb. 15, 8^h 42^m to 8^h 52^m Potsdam Mean Time.

In this exposure the spectrum was kept linear, and the great extension of the violet end is shown.

Plate No. 4. 1892, Feb. 15, 10^h 32^m to 11^h 37^m Potsdam Mean Time.

Taken with a larger spectrograph on the 11-inch refractor, simultaneously with the hydrogen spectrum. The photograph is so far unsuccessful that the slit was not correctly placed in the focus of the Hγ rays, and in consequence of the large chromatic aberration in the violet of the visually corrected objective, the spectrum at Hγ is very broad and weak. Only this much can be determined from the photograph;—that the greatly widened Hγ line of the star spectrum is traversed on the more refrangible side by the artificial hydrogen line, and that the line is displaced 0.7μμ to 0.8μμ toward the red; the middle of the broad dark hydrogen line, on the other hand, is displaced 1.0 μμ from the artificial line toward the violet.

Plate No. 5. 1891, Feb. 17, 9^h 15^m to 9^h 35^m Potsdam Mean Time.

The spectrum of α Aurigæ is photographed on both sides of the Nova's spectrum for determining the displacement of lines.

REGION OF H AND K.

Microm. rev. r		Remarks.
0.69		Broad dark line with very diffuse edges.
1.03	Bright line?	
1.13		
1.28	Bright line, more diffuse on violet side.	
1.75		
1.83	Dark line; narrow.	
2.15	Broad bright line.	
2.86	Broad bright line, diffuse toward violet.	
3.01		Broad dark line.
3.30	Bright line; weak narrow.	
3.56		
3.56		Broad bright line.
3.71	maxima	
3.90		
4.10		
4.63		Broad dark line.
4.91	Bright line; weak.	
5.18		
5.18		Broad bright band.
5.34	maxima	
5.53		
5.84		

REGION OF Hδ.

Microm. rev. r		Remarks.
0.27		Dark band.
0.53	line barely visible.	
0.79		
0.79		Broad bright band.
0.90	maxima; brightest at 1.06.	
1.06		
1.25		
1.47		

REGION OF Hγ.

Microm. rev. r		Remarks.
0.40		Dark band.
0.61	Bright line, well marked.	
0.84		
0.84		Broad bright band.
0.90	maxima, most intense at 0.90.	
1.07		
1.27		
1.48?		
1.65		

Plate No. 6. 1892, Feb. 20, 6^h 35^m to 7^h 5^m Potsdam Mean Time.

A remarkably fine photograph.

REGION OF H AND K.

Microm. rev. r		Remarks.
0.62	Broad dark line.	
1.00		
1.00	Bright line?	
1.48	Very broad, bright line, diffuse on both sides.	
1.98	Bright line.	Blend together.
2.23	Bright line.	
2.73	Very broad bright line.	
2.95		Broad dark line.
3.25	Bright line.	
3.55		
3.60	3 broad bright lines, blended into a broad band. The least refrangible is the most intense.	
3.75		
3.95		
4 57		Dark band.
4.90	Bright line.	
5.14		
5.14		Bright band.
5.25	maxima	
5.55		
5.76		

REGION OF Hδ.

Microm. rev. r		Remarks.
0.20		Dark band.
0.55	Very strong bright line.	
0.78		
0.78		Bright band.
0.87	Maxima very sharply marked; the less refrangible is the weaker.	
1.15		
1.38		

REGION OF Hγ.

Microm. rev. r		Remarks.
0.33		Dark band.
0.61	Bright line, very distinct.	
0.84		
0.84		Bright band.
0.97	Very broad bright max.	
1.24	Broad maximum less intense and broad than the other.	
1.65		

Plate No. 7. 1892, Feb. 20, $10^h\ 35^m$ to $11^h\ 0^m$ Potsdam Mean Time.

The exposure was unfortunately interrupted by clouds, and the photograph is decidedly inferior to the last. Nevertheless, the division of the bright lines can be recognized in this plate also.

Plate No. 8. 1892, Feb. 23, $9^h\ 30^m$ to $9^h\ 55^m$ Potsdam Mean Time.

The photograph is rather weak. Only the region of Hδ and Hγ is measured.

REGION OF Hδ.

Microm. rev. r	Remarks.	
0.15		Dark band.
0.57	Bright line.	
0.80		
0.83 1.15	maxima in the bright Hδ line; very distinct.	

REGION OF Hγ.

Microm. rev. r	Remarks.	
0.29		Dark band
0.60	Bright line; somewhat diffuse.	
0.85		
0.93 1.20	maxima in the bright Hγ line.	

Plate No. 9. 1892, Feb. 23, $11^h\ 15^m$ to $12^h\ 0^m$ Potsdam Mean Time.

Excellent plate, with β Aurigæ as comparison spectrum. The spectrum was made broad, whereby the Hγ and Hδ lines and the detail in their vicinity are given greater distinctness. The violet is, on the contrary, weak.

REGION OF H AND K.

Microm. rev. r	Remarks.	
1.10 : 1.80 :	Bright place in the very weak spectrum.	
2.00	Broad bright place.	
2.25	Broad bright place; middle.	
2.57 2.90	Broad bright place.	
2.90		Dark band.
3.29	Bright line; easily seen.	
3.55		
3.55		Bright band.
3.59	Very narrow maximum.	
3.84	Second very broad and much brighter max.	
3.98		
4.58		Dark band.
4.91	Bright line.	
5.15		
5.15		Broad bright line.
5.23	Very narrow maximum.	
5.54	Very broad maximum.	
5.80		

REGION OF Hδ.

Microm. rev. r	Remarks.	
0.15		Dark band.
0.57	Bright line.	
0.70		
0.70		Bright line.
0.88 1.15	maxima.	
1.33		

REGION OF Hγ.

Microm. rev. r	Remarks.	
0.25		Dark line.
0.60	Bright line; weak and broad.	
0.78		
0.78		Bright line.
0.90	maximum.	
1.18	Second max. like the first.	
1.45		

Plate No. 10, 1892, Feb. 25, $6^h\ 45^m$ to $7^h\ 20^m$ Potsdam Mean Time.

Excellent photograph. Spectrum of β Aurigæ on both sides, very close to the spectrum of the Nova; consequently very exact measurments of displacement.

REGION OF H AND K.

Microm. rev. r		Remarks.
1.18		Bright, broad line; diffuse.
1.48	Brighest phase	
1.82		
2.62	Bright line.	
2.88	Bright line.	
2.88		Dark line.
3.27	Bright line very prominent	
3.54		
3.54		Bright line.
3.65	Maximum weak	
3.84 3.90	Max. impression exactly that of a double line	
4.02		
4.61		Dark line.
4.90	Bright line	
5.18		
5.18		Bright line.
5.22	Maximum; narrow.	
5.45	Max.; very broad and bright.	
5.57		

REGION OF Hδ

Microm. rev. r		Remarks.
0.20		Dark line.
0.56	Bright line	
0.78		
0.78		Bright line.
0.92 1.17	Maxima	
1.30		

REGION OF Hγ

Microm. rev. r		Remarks.
0.29		Dark line.
0.60	Bright line	
0.78		
0.78		Bright line.
0.90	Maximum.	
1.12	Max.; brighter than the last.	
1.45		

Plate No. 11, 1892, Feb. 26, 7^h Potsdam Mean Time.

Weak plate, taken through clouds; not suitable for precise measurement. β Aurigæ as comparison spectrum. It is noteworthy that H and Hγ are almost equal in intensity; Hδ, on the contrary, is considerably weaker.

Plate No. 12, 1892, March 2, 9^h 30^m to 10^h 30^m Potsdam Mean Time.

Successful photograph, highly interesting on account of the great changes which have taken place in the violet part of the spectrum, and particularly in the K line. β Aurigæ as comparison spectrum.

REGION OF H AND K.

Microm. rev. r		Remarks.
0.58 0.98	Dark line with very diffuse borders.	
1.26	Dark line; narrow.	
1.28		Bright line.
1.55	Middle and most intense place.	
1.86		
2.65 3.30	Rather bright place in continuous spectrum. At 3.17r perhaps a narrow line.	
3.33 3.53	Dark line; very sharply marked	

Microm. rev. r		Remarks.
3.53		Bright line.
3.66 3.89	Maxima	
4.08		
4.53	Weak bright line; narrow.	
4 58		Dark line.
4.88	Bright line, somewhat diffuse, perhaps double (4.80r, 4.93r)	
5.18		
518		Bright line.
5.25	Max., narrower and weaker than the following.	
5.53	Maximum.	
5.74		

REGION OF Hδ.

Microm. rev. r	Remarks.	
0.13		Bright line.
0.56	Bright line; somewhat diffuse toward the violet; perhaps 2 lines.	
0.80		
0.80		Bright line.
0.87	Maxima	
1.10		
1.38		
(1.43)	Entirely isolated line perhaps a fault in the plate.	

REGION OF Hγ.

Microm. rev. r	Remarks.	
0.30		Dark line.
0.55	Bright lines blended together.	
0.68		
0.85		
0.85		Bright line.
0.92	Maxima	
1.15		
1.39		
1.52		

Plate No. 13, 1892, March 3, 7h 0m to 8h 0m Potsdam Mean Time.

Excellent plate, with β Aurigæ for comparison spectrum.

REGION OF H AND K.

Microm. rev. r	Remarks.	
0.60	Dark line with very diffuse borders.	
0.95		
1.25 :	Dark, diffuse line.	
1.50	Brightest place in a broad, very diffuse band.	
2.39	Rather dark place in spectrum.	
2.58		
3.35	Dark line very sharply bounded.	
3.55		
3.55		Bright line quite sharply bounded on the red side.
3.63	Maxima all somewhat vague.	
3.80 ?		
3.95		
4.08		
4.50	Narrow bright line.	
4.56		Dark line.
4.78	Two delicate bright lines, blended together.	
4.94		
5.19		
5.19		Bright line.
5.28	Maximum; narrow.	
5.50	Max.; broad and strong.	
5.85		

REGION OF Hδ.

Microm. rev. r	Remarks.	
0.15		Dark line
0.48	Weak and broad bright line with two maxima.	
0.62		
0.85		
0.85	Max. not well separated	Bright line.
0.91		
1.13		
1.39	Perhaps a line.	

REGION OF Hγ.

0.32		Dark line.
0.60	Broad, diffuse; not certainly double.	
0.80		
0.80		Bright line.
0.94	Max. narrower than the following.	
1.13		
1.44		
1.51		

Plate No. 14, 1892, March 4, 7h 0m to 8h 0m Potsdam Mean Time.

One of the finest plates obtained. Spectrum kept somewhat wide, and hence rather weak in the violet. Reliable measures with comparison spectrum of β Aurigæ.

REGION OF H AND K.

Microm. rev. r	Remarks.	
1.14	Quite diffuse.	A piece of the continuous spectrum.
2.17	Diffuse.	
2.67	Broad bright line; weak.	
3.17	Perhaps two bright lines; otherwise a pretty broad band, weaker than the preceding line.	
3.55		Bright band.
3.59	Maximum.	
3.90	Max.; weaker than the preceding.	
4.04		
4.53		Dark line.
4.88	Broad bright line; quite weak.	
5.18		
5.18		Bright line.
5.26	Maximum; weak.	
5.51	Max.; very bright and broad.	
5.75		

REGION OF Hδ.

Microm. rev. r	Remarks.	
0.13		Dark line.
0.55	Broad bright line; distinctly marked (intense).	
0.79		
0.79		Bright line.
0.91 1.13	maxima; equally bright.	
1.35		

REGION OF Hγ.

Microm. rev. r	Remarks.	
0.23		Dark line.
0-60	Bright line, not very prominent.	
0.85		
0.85		Bright line.
0.91 1.20	maxima; equally bright.	
1. 51	Fairly sharp borders.	

Plate No. 15, 1892, March 5, 7^h 20^m to 7^h 40^m Potsdam Mean Time.

Spectrum of the Nova somewhat weak. The spectrum of the Moon with full slit-width and with 10 seconds exposure was photographed on the star spectrum. The displacement of the bright hydrogen lines Hγ, Hδ and H, is shown very clearly in this way. Hγ and Hδ in the lunar spectrum coincide exactly with that maximum of the corresponding bright lines in the spectrum of the Nova which lies toward the violet side.

Plate No. 16, 1892, March 9, 7^h $37^m.5$ to 8^h $22^m.5$ Potsdam Mean Time.

As in the last plate, the lunar spectrum is photographed also, but it is so intense that the spectrum of the Nova is hardly recognizable.

Plate No. 17, 1892, March 9, 9^h 50^m to 10^h 10^m Potsdam Mean Time.

Like the last plate. The star spectrum can be seen better; but there is nothing in this plate worthy of remark.

Plate No. 18, 1892, March 13, 7^h 0^m to 8^h 0^m Potsdam Mean Time.

Spectrum kept quite linear. The continuous spectrum has almost completely disappeared, and the bright lines appear as isolated, somewhat elongated knots of light. The following lines could be measured with certainty (compare with a table given further on, of all the lines measured in the spectrum when the star was still brighter):

K	933μμ	Hδ	410μμ	426 429 431 μμ	Hγ 434μμ
H	397		418		452
	407		423		456
					458

Plate No. 19, 1892, March 16, 7^h 30^m to 9^h 0^m Potsdam Mean Time.

The plate still shows many lines like those of the last plate. β Aurigæ as comparison spectrum. The following lines were measured:

α 389$\mu\mu$
K 393
397
407
$H\delta$ 410
418
421
424

429$\mu\mu$
$H\gamma$ 434
442
452
456
458

The positions of the hydrogen lines, from the mean of several measurements of the spectra of the comparison stars α and β Aurigæ, taking into account the motions of the Earth and Sun at the time of observation, are, $H = 5.36r$, $H\delta = 0.92r$, $H\gamma = 0.92r$. Measurements of the difference K — H in the spectra of various other stars, in which the K line is visible, give $K = 3.73r$. If we now form with these values the differences of the measured lines, we obtain the displacements of the lines in the spectrum of the Nova in micrometer revolutions, or, with the aid of the table on page 902, in wave-lengths; and finally, by means of the values following, the motion corresponding to these displacements in miles:

1 $\mu\mu$ at K corresponds to 473.8 miles.*
" H " 469.6 "
" $H\delta$ " 454.4 "
" $H\gamma$ " 429.3 "

I shall now bring the observations together in tabular form, remarking that a negative motion signifies approach, a positive one recession, with respect to the Sun; further that plates marked (*) have a comparison spectrum photographed on them alongside of the spectrum of the Nova, and are therefore available for determining the relative motion of the Nova and Sun, while the other observations cannot be regarded as decisive in this respect.

In these plates the starting point of the measurements was so chosen that they could be connected in the most exact manner possible with those first mentioned, under the assumption of constancy in the positions of the fine bright lines which appear in the dark K, H, $H\gamma$ and $H\delta$ lines. In regard to the relative positions of the individual measured points, all the observations are of equal value.

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* English statute miles.

K

No. of Plate.	DISPLACEMENT IN REV.			DISPLACEMENT IN $\mu\mu$			VELOCITY IN MILES.		
	Bright line in dark.	First Max.	Second Max	Bright line in dark.	First Max.	Second Max.	Bright line in dark.	First Max.	Second Max.
1	− 0.45	− 0.04	+ 0.12	− 0.95	− 0.08	+ 0.25	− 452	− 37	+ 120
2	− 0.43	− 0.08	+ 0.07	− 0.90	− 0.17	+ 0.15	− 424	− 78	+ 69
5*	− 0.43	− 0.02	+ 0.17	− 0.90	− 0.04	+ 0.36	− 424	− 18	+ 171
6	− 0.48	− 0.06	+ 0.22	− 1.01	− 0.12	+ 0.46	− 479	− 55	+ 217
9	− 0.44	− 0.14	+ 0.11	− 0.92	− 0.29	+ 0.23	− 438	− 138	+ 111
10*	− 0.46	− 0.08	+ 0.15	− 0.97	− 0.17	+ 0.32	− 461	− 78	+ 152
12*		− 0.07	+ 0.16		− 0.15	+ 0.34		− 69	+ 161
13*		− 0.10	+ 0.22		− 0.21	+ 0.46		− 101	+ 217
14*		− 0.14	+ 0.17		− 0.29	+ 0.36		− 138	+ 171
	− 0.45	− 0.08	+ 0.15	− 0.94	− 0.17	+ 0.33	− 447	− 78	+ 152

H

1	− 0.41	− 0.06	+ 0.16	− 0.89	− 0.13	+ 0.35	− 420	− 60	+ 166
2	− 0.48	− 0.11	+ 0.19	− 1.05	− 0.24	+ 0.41	− 493	− 111	+ 194
5*	− 0.45	− 0.02	+ 0.17	− 0.98	− 0.04	+ 0.37	− 461	− 18	+ 175
6	− 0.46	− 0.11	+ 0.19	− 1.00	− 0.24	+ 0.41	− 470	− 111	+ 194
9	− 0.45	− 0.13	+ 0.18	− 0.98	− 0.28	+ 0.39	− 461	− 134	+ 184
10*	− 0.46	− 0.14	+ 0.09	− 1.00	− 0.31	+ 0.20	− 470	− 147	+ 92
12*	− 0.48	− 0.11	+ 0.17	− 1.05	− 0.24	+ 0.37	− 493	− 110	+ 175
13*	− 0.50	− 0.08	+ 0.14	− 1.09	− 0.17	+ 0.31	− 507	− 78	+ 147
14*	− 0.48	− 0.10	+ 0.15	− 1.05	− 0.52	+ 0.33	− 493	− 101	+ 157
	− 0.46	− 0.10	+ 0.16	− 1.01	− 0.21	+ 0.35	− 475	− 97	+ 166

Hδ

1	− 0.37	− 0.02	+ 0.23	− 0.94	− 0.05	+ 0.59	− 429	− 23	+ 267
5*	− 0.39	− 0.02	+ 0.14 + 0.33	− 0.99	− 0.05	+ 0.36 + 0.84	− 447	− 23	+ 161 + 383
6	− 0.37	− 0.05	+ 0.23	− 0.94	− 0.13	+ 0.59	− 429	− 60	+ 267
8	− 0.35	− 0.09	+ 0.23	− 0.89	− 0.23	+ 0.53	− 406	− 106	+ 267
9	− 0.35	− 0.04	+ 0.23	− 0.89	− 0.10	+ 0.59	− 406	− 46	+ 267
10*	− 0.36	0.00	+ 0.25	− 0.92	0.00	+ 0.64	− 420	− 0	+ 290
12*	− 0.36	− 0.05	+ 0.18	− 0.92	− 0.13	+ 0.46	− 420	− 60	+ 207
13*	− 0.44 − 0.30	− 0.01	+ 0.21	− 1.12 − 0.77	− 0.03	+ 0.54	− 507 − 350	− 14	+ 244
14*	− 0.37	− 0.01	+ 0.21	− 0.94	− 0.03	+ 0.54	− 429	− 14	+ 244
	− 0.37	− 0.03	+ 0.22	− 0.93	− 0.08	+ 0.54	− 424	− 37	+ 258

Hγ

No. of Plate.	DISPLACEMENT IN REV.			DISPLACEMENT IN $\mu\mu$			VELOCITY IN MILES.		
	Bright line in dark.	First Max.	Second Max.	Bright line in dark.	First Max.	Second Max.	Bright line in dark.	First Max.	Second Max.
1	− 0.32	− 0.02	+ 0.24	− 1.04	− 0.07	+ 0.78	− 447	− 32	+ 337
5*	− 0.31	− 0.02	+ 0.15 + 0.35	− 1.01	− 0.07	+ 0.48 + 1.13	− 433	− 32	+ 207 + 484
6	− 0.31	+ 0.05	+ 0.32	− 1.01	+ 0.16	+ 1.04	− 433	+ 69	+ 447
8	− 0.32	+ 0.01	+ 0.28	− 1.04	+ 0.03	+ 0.91	− 447	+ 14	+ 392
9	− 0.32	− 0.02	+ 0.26	− 1.04	− 0.07	+ 0.85	− 447	− 32	+ 364
10*	− 0.32	− 0.02	+ 0.20	− 1.04	− 0.07	+ 0.65	− 447	− 32	+ 281
12*	− 0.37 − 0.24	0.00	+ 0.23	− 1.20 − 0.78	0.00	+ 0.75	− 516 − 336	0	+ 323
13*	− 0.32	+ 0.02	+ 0.21	− 1.04	+ 0.07	+ 0.68	− 447	+ 32	+ 290
14*	− 0.32	− 0.01	+ 0.28	− 1.04	− 0.03	+ 0.91	− 447	− 14	+ 392
	− 0.32	0.00	+ 0.25	− 1.03	− 0.01	+ 0.82	− 442	− 5	+ 350

Considering the great difficulty of fixing the by no means sharply bounded maxima, and of measuring in such a short spectrum ($0.04r = 0.01mm$ corresponds in the average to a motion of 46 miles per second), the observations agree quite well, and prove a remarkable constancy in the relative distances of the lines which were measured.*

The following table contains the widths which I have found for the bright and the dark Hδ and Hγ lines from the mean of all the measured plates; also the displacement of the middle points of these lines with respect to the lines of the comparison spectrum (after reduction to the Sun), from the mean of plates 5, 10, 12, 13 and 14, and the velocities corresponding to these displacements in English miles.

LINE.	Breadth in $\mu\mu$	Displacem't of the middle in $\mu\mu$	Velocity.
Hδ, bright............	1.49	+ 0.44	+ 198
Hγ, bright............	2.28	+ 0.85	+ 364
Hδ, dark...............	1.53	− 1.10	− 498
Hγ, dark...............	1.65	− 1.15	− 493

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* I should not wish to leave unmentioned that, with Dr. Scheiner I made some preliminary measures of the plates last year which gave the result − 433, − 41, + 281 miles (relatively to the Sun). A. N. 3079.

In regard to the appearance of the dark lines I have still to remark that on several plates the impression which these plates gave me was this; that they were partially covered by the bright lines where they came in contact with the latter, *i. e.*, on their less refrangible sides, and that perhaps the centre was therefore indicated by the fine bright line. The idea that the fine line is to be regarded as a reversal at once suggests itself. However, other plates, particularly those which were longer exposed, show that the maximum darkening in the lines lies somewhat to the violet side of the fine bright lines. If these places are regarded as the centres of the dark lines their displacement corresponds to a velocity of 507 miles per second.*

Finally, I have collected in the following table, the wave-lengths of the brightest lines in the visible and photographic spectrum of the Nova, deduced for the most part from repeated measurements, and have added for comparison the brightest lines in the chromosphere spectrum according to Young.

Lines in Spectrum of the Nova.	Remarks.	Chromosphere Lines
μμ		
705	Bright line	705.6
656.2	Very bright line	Hydrogen, C
568.6*	At first broad and very bright	Sodium, D
531.7	Quite bright line	Corona line (Fe)
528 : 523 :	Fairly bright lines	528.5 (Fe, Ti) 523 5 (Fe, Mn, Zn)
516.7	Bright, very broad, diffuse on both sides..	518.4 517.2 516.9 516.8 (Mg *b* ?)
501.6	Bright, broad	501.9 501.6 (Fe, Ni, Ti)
492.5 492.3	Line, somewhat more diffused on red side measured on plate 1 only	493.4 492.4 492.2 491.9 (Ba, Fe, Zn)
486.2	Broad, bright	Hydrogen, F
....	On plate 2 several lines can be recognized.	
462.8	Broad bright line, recognizable on plate 2 only	463.0 (Fe, Ti, N)
458.3	Broad, bright line	458.4 (Fe)
455.7	Broad line	456.6 456.4 456.0 455.6 455.4 455.0 (Fe, Ba, Ti)

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* A lithographed plate in the original shows the appearance of the principal measured lines on the best plates.

Lines in Spectrum of the Nova.	Remarks.	Chromosphere Lines.
453.0 452.0	Broad bright line in spectrum	453.4 453.3 452.5 452.3 (Fe, Ba, Ca, Ti)
450.7	Middle of a group of lines measured on plate 6 only	450.2 (Ti)
449.5 448.0	Broad bright band	449.2 (Mg) 449.0 (Fe)
447.3	Broad line, hard to fix	448.1 (Mg, Fe) 447.2 (Ce) 447.0 (Fe, Ti)
444.5	Middle of a group of lines	444.4 (Fe, Ti)
443.5	Broad bright line	
441.7	Broad bright line	
438.3	Bright place in spectrum	439.5 438.5 437.6(Fe) 437.5(Fe)
434.1	Very bright line, 2 maxima	Hydrogen, $H\gamma$
431.5	Broad bright line	
428.8	Broad bright line	
426.2	Bright line very broad	
423.0	Broad bright line	423.6 (Fe) 423.4 (Fe, Ca)
417.6	Very broad bright line	
415.8	Measured on plate 6 only	
412.5	Measured on plate 5 only	
410.2	Broad, bright, 2 maxima	Hydrogen, $H\delta$
406.7	Broad bright place in spectrum; measured on plate 6 only, but perceptible on plates 18 and 19 also	
396.9	Very broad; 2 maxima	Hydrogen, H (Fe, Ca)
393.4	Broad, 2 to 3 maxima	K (Fe, Ca)
388.9	Broad and very bright	Hydrogen, α
383.5	Broad bright line	Hydrogen, β

[*] So printed in the original; perhaps 586.6 or 589.6.—*Tr.*

TO BE CONTINUED.

HYDROGEN ENVELOPE OF THE STAR DM. + 30° 3639.[*]

W. W. CAMPBELL.

The 9.3 magnitude star DM. + 30° 3639 is surrounded by an extensive hydrogen envelope. This star is of the Wolf-Rayet type, and its spectrum is very rich in bright lines, about thirty having been observed by me between wave-lengths 656 and 426. The most striking features of the visual spectrum are the continuous spectrum, the bright line at λ 5694, the bright blue band at λ 4652 and the very bright hydrogen $H\beta$ line. When the appara-

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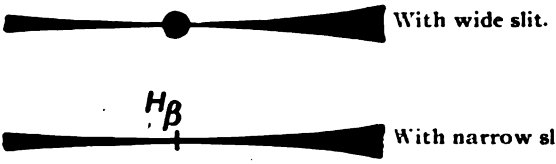
[*] Communicated by the author.

tus is in focus for the different parts of the spectrum referred to, the line at λ 5694 is a very small round image of the star; the band at λ 4652 is broad and lies wholly upon the narrow continuous spectrum: but the Hβ line, observed with a narrow slit, is a long line extending a very appreciable distance on each side of the continuous spectrum; and with an open slit is a large circular disc about 5″ in diameter. The appearance of the Hβ line is best shown by the accompanying sketch.



The same appearance is noticeable in the faint Hγ and very faint Hα lines. It is not noticeable in the other lines of this spectrum, nor has it been seen seen in the spectra of any other stars of this type. It is due to an envelope of incandescent hydrogen. Whether the large disc is wholly due to an unusually extensive atmosphere, or in part to proximity to the solar system, will be tested by further observation to be made here.

The existence of this hydrogen envelope can hardly fail to have an important bearing upon the theory of bright line stars.

MT. HAMILTON, Oct. 1.

THEORY OF THE SUN.*

A. BRESTER, JR.

In a memoir published in 1892 by the Royal Academy of Sciences of Amsterdam, and entitled "Theory of the Sun," I have endeavored to show that, if the ideas already firmly established and generally received at the present time as to the gaseous nature of the Sun and the cloud-like state of the photosphere have not yet led to any plausible explanation of the incessant and more or less irregular or periodic phenomena exhibited by the Sun, the fault rests solely in the hypothesis of solar eruptions; an hypothesis which, at first suggested by the deceptive appearance of a certain variety of prominences, and strongly supported

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* Read at the Congress of Astronomy and Astro-Physics, Chicago, August, 1893.

by the ordinary interpretation of the displacement of spectral lines, is in direct contradiction with many phenomena.

In rejecting this hypothesis we arrive at the conception of a relatively tranquil gaseous Sun, which is composed, according to the memorable discovery of Kirchhoff, of the same matter as our Earth. It is then possible to discover, according to the well known properties of this matter, what is the cause of its immobility, and to demonstrate that this same cause, which keeps the mass in repose, must also produce "chemical luminescence" and thereby moving flashes in the tranquil matter that have often the deceptive appearance of great material eruptions.

Such is my new chemical theory. If I introduce here some of its salient points, it is in the hope that their presentation at the Congress at Chicago will encourage some investigators to study my theory itself in the memoir to which I have referred.

Let us see in the first place what are the arguments which should lead us to acknowledge the tranquility of the Sun's interior and the character, often so deceptive, of the prominences which have been called "eruptive."

1. *The continuous stratification of the solar atmosphere*, which in that very place where the prominences traverse it without cessation, preserves indefinitely the same metallic vapors buried in its depths. This stratification of solar gas is an established fact shown by the spectroscope. If the metallic vapors, which are seen only in the depths of the chromosphere, were actually to rise into the higher regions of the solar atmosphere, it is not clear why their spectral rays should not appear there, when the rays of hydrogen, for example, are shown so plainly. We know in fact there are no vapors which exhibit their lines more easily than metallic vapors, and that those of incandescent hydrogen on the contrary are shown with difficulty. It is also doubtful whether hydrogen, even at its great temperature while burning in excess in oxygen, is sufficiently heated to produce lines. The experiments which Plücker and, quite recently, Liveing* have made to decide this question, have given contradictory results.

We have, moreover, no reason for admitting that there is a rapid diminution in temperature in the solar atmosphere, which is still incandescent in the most remote regions of the corona, and there, when by chance such comets as that of September, 1882, and that of Wells, have approached very near the Sun, we have

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* Plücker, *Pogg. Ann.*, 116, p. 48. Liveing, *Phil. Mag.*, Oct. 1892. On Plücker's supposed detection of the line spectrum of Hydrogen in the oxy-hydrogen flame.

been shown as a proof of the great reinforcement of their heat, the vaporization of sodium and iron in their mass. Now if an approach to the Sun renders iron itself vaporous and spectroscopically visible in the infinitely rarified substance of a comet, it is not clear how the same metal at a shorter distance from the Sun, if really present in the upper layers of the solar atmosphere, could be incapable of there manifesting its lines.

The Sun's atmosphere then is not homogeneous* but has a real stratified structure and in its upper layers the lightest elements predominate. But a similarly stratified gaseous structure does not obtain except in an absolutely tranquil gas. Under this condition it is also foreseen in the kinetic theory of gases. It is absolutely incompatible with the hypothesis of solar convulsions. We know moreover that in our own atmosphere, movements a thousand times smaller are quite sufficient to prevent the least stratification.

2. *The tranquility already generally admitted of those prominences which are known as quiescent* and which, floating like clouds in the upper regions of the Sun's atmosphere, kindle and die out, now and then without any connection binding them to the distant chromosphere. According to Young, "the general appearance of these objects indicates that they originate where we see them and are formed by a local heating or by some luminous agitation of the hydrogen already present, and not by a transportation of matter, taken from a distance."† When the prominence disappears, says Lockyer,‡ it is not that the matter disappears; it changes its state, and this change is chiefly in temperature. Although Young and Lockyer have not mentioned the combination of dissociated elements as a cause for "the luminous agitation in the hydrogen already present," their explanation of the quiescent prominence is for the rest quite the same as that which I would also apply to all prominences without exception.

3. *The stratification of eruptive prominences* which in showing us certain metallic vapors near their bases only, also harmonize poorly, it seems to me, with the idea of homogeneous gaseous masses shooting in a few minutes from the depths of the photosphere to elevations of hundreds of millions of meters. It cannot be admitted that in such eruptions gravitation keeps these vapors from rising higher than a minute of arc, while the lighter elements alone continuing their ascent, sometimes quickly

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* Ranyard: *Knowledge*, 1893, p. 30.

† Young: The Sun, p. 166.

‡ Lockyer: Chemistry of the Sun, p. 415.

attain height eight or more times greater. It does not seem, moreover, that the small height to which these heavier metals appear to rise depends always on the violence of the eruption as one would naturally suppose. The great prominence of July 1, 1887, displayed no metallic lines, while the low prominences of May 21, 1887, showed many of them.[*] In the prominence of June 17, 1891, Trouvelot and Fényi both observed that the number of metallic lines was not at all proportionate to the exceptional violence of the supposed eruption,[†] and upon the authority of Secchi, it is ordinarily the small eruptions which are remarkable for their abundance of metallic vapors.[‡] Surely there is in this stratification of eruptive prominences something which makes us think rather of some "luminous agitation" of a stratified atmosphere already present than of a sudden eruption of "matter brought from a distance."

4. *The forms of the prominences* which, chiefly when they are disrupted, and present constant and irreconcilable changes of direction, are incapable of giving us the idea of an eruption or of an explosion of any kind. Especially when these prominences, separated into fantastic and dissimilar filaments, are of great dimensions (as that of Oct. 3, 1892, for example, which extended over 30° of the Sun's limb and reached an elevation greater than half the solar radius), it becomes impossible to recognize there a real material movement. Is it not surprising also that Fényi in describing a similar prominence, probably the largest ever observed, has taken opportunity to call attention to my new theory in which "neither the ragged outlines of the image nor their great extent present any difficulties."[§]

I am well aware that the prominences are not always of such fantastic forms and that many of them too have flame-like jets much resembling veritable eruptions. But this apparent resemblance must be accepted with much caution. The cirrous clouds of our own atmosphere also often seem to be arranged by some powerful current. But this phenomenon is surely deceptive when it is seen to be produced by the cirri forming suddenly and then spreading almost instantaneously over the greater part of the sky with their filaments straight or gracefully curved, parallel or divergent.[‖] All those prominences, moreover, which show us

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[*] Publications of the Haynald Observatory, VI Heft. 1892, pp. 13 and 23.

[†] Fényi, S. J., *Mem. d. Soc. d. spettrosc. Italiani*, Vol. XXI (1892) Tav. 276.

[‡] Secchi, *Le Soleil*, II, p. 149.

[§] Fényi, *Mem. d. Soc. d. Spettrosc. Italiani*, Vol. XXI (1892). Note sur une Protubérance excessivement grande observée le 3 Oct., 1892, à l'observ. Haynald.

[‖] W. v. Bezold: *Himmel und Erde*, Oct., 1892. Secchi: *le Soleil* I, p. 119. Liais: *l'Espace celeste*, p. 49.

sheafs and particularly jets clearly defined and arranged in fans or radiating systems, have indeed the appearance of eruptions. But these appearances represent the facts of the case only when we suppose them to be produced by something analogous to sky-rockets or to divergent jets of a fountain of burning liquid. But as spectral analysis teaches us that they are produced by an incandescent gas, I cannot believe that the forms result from actual motion. Let us consider, for instance, the prominence which Secchi has reproduced in Fig. 5 of Plate E of his treatise on the Sun. We see there seven diverging rays in the shape of a fan. Secchi* says, "These rays were *perfectly straight* and very clearly defined; one of them shot out with a velocity of 190 kilometres per second and attained a height of 1′ 25″, almost six times the diameter of the Earth." On other occasions perfectly straight rays were projected with a still more startling velocity. Quoting again from Secchi: "The first of July we saw some which in four minutes ran up to 2′ 20″." Now is it conceivable that a gas shooting up from a gaseous Sun can take the form of jets which remain clearly outlined and perfectly straight up to a distance equal to ten times the diameter of the Earth? Can it be admitted that there are on the gaseous and cloudy surface of the Sun, holes with resisting walls† drawing out the ejected gas into threads? Is it possible that a streamer of gas thrown obliquely into the solar atmosphere can there preserve its primitive form with "definite outlines" to a distance of many terrestrial radii? Has such a filament no appreciable force of expansion, even in the rarified upper layers of the atmosphere? Does it meet with no sensible resistance in this gaseous medium? And is it no longer subject to the least influence of solar gravitation, as appears to be the case, since the filament, although much inclined, remains "perfectly straight" over a length equal to twenty of the Earth's radii.

If at other times streamers of incandescent gas twist into spirals or curve gently back again toward the surface, still (sharply defined as before) it is not any easier to see in them the portrayal of an actual movement. All these filiform prominences, straight or curved, are of the same general type as the filamentary clouds of our own atmosphere—of the same type also as those slender jets which one sees so often‡ in those clouds completely detached from the chromosphere, which we have already considered above,

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* Secchi, *le Soleil* II, p. 59.

† Lockyer, *Chem. of the Sun*, p. 423. Young, *The Sun*, p. 169.

‡ Secchi, *le Soleil*, II, p. 69.

and which by common consent have long been considered as "quiescent prominences."

5. *The improbable velocities of the supposed movements.*—These velocities are not only improbable in reaching such marvelous rates of several hundreds or even of more than a thousand kilometers per second:[*] but they are not less so when they ceaselessly and capriciously change their rate and direction, now rapidly diminishing, now as rapidly augmenting. Though Ranyard has attempted to demonstrate that the movement of a prominence observed by Young, Oct. 7, 1880, seemed to agree in some small measure with that of a projectile restrained in its course by the gravitation of the sun,[†] there have been few observations of this kind, while I know of many where a careful study of the velocities[‡] showed them to be absolutely incompatible with every hypothesis of an eruption, of an explosion, or even of any form of electric repulsion. It is quite remarkable too that spectroscopic investigations of small eruptions, of 20″ for instance, show in them now and then great velocities (426 kilometres per second) while at other times no motion in the line of sight is observed in enormous eruptions like that the third of October last.[§]

6. *The very brief duration of some prominences, their rapid changes of form and their sudden extinction*, at times in two minutes. This extinction is the more remarkable that the most slender incandescent jets which can be distinguished are nevertheless 200 or 300 k. in thickness.[¶] Secchi, Zöllner, Young, Lockyer and Fényi[**] have given many descriptions of these solar *dissolving views*. The rapidity of these changes to the sight is such that Secchi himself, after describing them, adds: "The cloudy masses (of the prominences) flash out so quickly and again so quickly dissolve that one is compelled to see in them a momentary transformation rather than a real transportation of ponderable matter.[††]

7. *The perfect quiet* which is observed (*A*) in the photosphere (sometimes even where it is unspotted[‡‡]) at a place bordering on

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[*] Fényi, *Mem. d. Soc. d. Spettrosc. Ital*, Vol. XXI (1892). Rapport sur les movements aussi singuliers qu'extraordinaires d'une protuberance observée le 17 Juin, 1891.

[†] Ranyard, *Monthly Notices*, Dec. 1880.

[‡] Fényi, *Protuberanzen beob. in J. 1887*, pp. 19-20.

[§] Fényi, *loc. cit.* p. 14. See also on p. 23 the difficulties of interpreting velocities in the line of sight, such as those exhibited by the enormous prominence of July 1, 1887.

[¶] Secchi, *le Soleil* II, p. 70.

[**] *Loc. cit.*, p. 23.

[††] Secchi, *le Soleil*, II. p. 108. Pl. E—figs. 5, 6. Pl. H—figs. 1, 3, 5, 7, 9, 11. Young, *The Sun*, figs. 62, 63. Lockyer, *Solar Physics*, figs. 92, 93; 135, 136.

[‡‡] Fényi, Deux eruptions considérables 5 et 6 Sept. 1888. *Mem. d. Soc. Spettros. Ital.* XXIII. (1889).

a gigantic prominence;[*] (*B*) in the solar atmosphere at a place even where several minutes previously there had occurred a terrific eruption;[†] (*C*) in the small clouds floating in the solar atmosphere and not stirring although in the immediate neighborhood of an extraordinary eruption.[‡]

The quiet maintenance of quiescent prominences often for so long a time is another proof of great atmospheric calm. But how can such a calm be produced if, according to Secchi, there are during a maximum period at least two hundred centres of eruptions in full activity on the surface of the Sun,[§] and if we believe with Young[||] that the Sun is always surrounded by flames innumerable.

8. *The sudden origin of metallic prominences at transcendent speed without visible connection with the distant chromosphere.* In this way appeared the great prominenceof June 17, 1891, showing at once an upward velocity of 485 k. per second, and a motion of 890 k. in the line of sight.[¶] "This time, however," says Fényi, "the masses in commotion were not observed to leave the surface, notwithstanding the fact that the same locality was continually watched." "In all probability," he adds, "the forces which occasioned the motion described originated at a certain height and suddenly acted upon masses which they there encountered." Do not such observations perfectly agree with my theory of the prominences, namely, that they are a sort of faint glow (*lueur*) originating spontaneously in quiescent matter? Here is still another observation of the same kind, mentioned by Fényi as a "marvellous fact." It is the sudden appearance, by no means rare, of great motion in the line of sight alone;[**] motions for example, which, although continuing with a velocity of 150k. a second during half an hour, produce nevertheless no displacement in the position of the prominence, and cannot possibly be attributed to currents in the matter of which the Sun is composed.

Rapidly moving isolated jets which appear so often and so suddenly, the so-called eruptive prominences seem to spring into existence spontaneously in the same manner. If the prominences

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[*] *Loc. cit.*

[†] Trouvelot. *l'Astr.*, IV, p. 441. Lockyer, *Chem. of Sun*, p. 415. Fényi, *Comptes rendus* 108, p. 889.

[‡] Fényi: *Memorie*, Vol. XXI, (1892), Sur une protuberance d'une hauteur énorme observée le 5 Mai à Kalocsa.

[§] Secchi, *le Soleil*, II, p. 80.

[||] Young, *The Sun*, p. 147.

[¶] Fényi, *Mem.* XXI, 1892, Rapport sur les movements aussi singuliers qu' extraordinaires d'une protuberance observée le 17 Juin, 1891. Tacchini, *Compt. rend.*, 9 Janv. 1893. N. F. Miller, ASTRONOMY AND ASTRO-PHYSICS, 1892, p. 615.

[**] Fényi, *loc. cit.* Mem. XX, 1891.

with ragged outlines result from the superposition of several prominences in the line of vision,* the difficulty of explaining their sudden simultaneous appearance as the effect of true eruptions is all the greater; since, if it is already difficult to admit that a single prominence may have an ultimate chromospheric connection concealed by some cooled opaque mass, that difficulty is still greater when several contemporary eruptions require this same hypothesis at the same time. The existence of these connections with the chromosphere is, to say the least, very doubtful. The argument runs like this, "These connections are surely there, but they cannot be seen because they are veiled by a cooler opaque mass which itself is invisible." Such an argument is not very convincing.

Besides the arguments which I have advanced against the hypothesis of solar eruptions, I have still another which, of itself, seems to me much more important than all the others together. The principal fact, already referred to, is that it is only necessary *to be freed from that sterile hypothesis, to accept a plausible chemical explanation of the principal solar phenomena.* In a comparatively quiet Sun the motions of even the largest prominences cease to be mysterious. And not only do the prominences then become infinitely more comprehensible, but it is soon seen that the cause of the prominences is also that of the spots, and of the coronal rays as well, and that this common cause is of such a nature as to distribute these phenomena periodically and, in parallel zones, over the surface of the Sun.

Such are the recent explanations which I have developed in my Memoir mentioned above. If the discussion which I have given them here is necessarily but brief, I hope nevertheless, to give it some new interest by an examination of the numerous observations which have been made without cessation since the publication of my Memoir, tending in general (I trust it will be seen) to confirm my theory.

ON THE THEORY OF STELLAR SCINTILLATION.†

LORD RAYLEIGH.

A complete investigation of atmospheric refraction can only be made upon the basis of some hypothesis as to the distribution of

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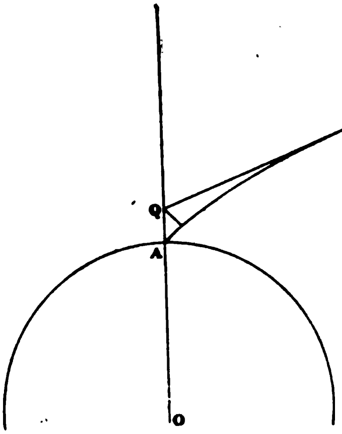
* Ranyard, *Knowledge*, Feb. 1893.

† Continued from p. 845, No. 119.

temperature; but, as has already been hinted, a second approximation to the value of refraction can be obtained independently of such knowledge and without difficulty. In Laplace's elaborate investigation it is very insufficiently recognized, if indeed it be recognized at all, that the whole difficulty of the problem depends upon the curvature of the Earth. If this be neglected, that is if the strata are supposed to be plane, the desired result follows at once from the law of refraction, without the necessity of knowing anything more than the condition of affairs at the surface.



For in virtue of the law of refraction,

$$\mu \sin \theta = \text{constant};$$

so that if θ be the apparent zenith distance of a star seen at the earth's surface, and $\delta\theta$ the refraction, we have at once

$$\mu_0 \sin \theta = \sin (\theta + \delta\theta), \tag{19}$$

from which the refraction can be rigorously calculated. If an expansion be desired,

$$\begin{aligned} \delta\theta = \sin \delta\theta &= \tan \theta \, (\mu_0 - \cos \delta\theta) \\ &= (\mu_0 - 1) \tan \theta \{ 1 + \tfrac{1}{2}(\mu_0 - 1) \tan^2 \theta \} \end{aligned} \tag{20}$$

is the second approximation.

When the curvature of the Earth is retained, so that the atmospheric strata are supposed to be spheres described round O, the centre of the Earth the appropriate form of the law of refraction is

$$\mu p = \text{constant}.$$

Thus, if A be the point of observation at the Earth's surface where the apparent zenith distance is θ, and if the original direction of the ray outside the atmosphere meet the vertical OA at the point Q,

$$\mu_0 \,.\, \mathrm{OA} \,.\, \sin\theta = \mathrm{OQ} \,.\, \sin(\theta + \delta\theta);$$

or if OA $= a$, AQ $= c$,

$$\mu_0 a \sin\theta = (a + c)\sin(\theta + \delta\theta) \tag{21}$$

If c be neglected altogether, we fall back upon the former equations (19), (20). For the purposes of a second approximation c, though it cannot be neglected, may be calculated as if the refraction were small, and the curvature of the strata negligible. If η be the whole linear deviation of the ray due to the refraction,

$$c = \eta/\sin\theta, \tag{22}$$

and, as in (16),

$$\eta = (\mu_0 - 1)\, l \sin\theta/\cos^2\theta, \tag{23}$$

so that

$$c = \frac{(\mu_0 - 1)l}{\cos^2\theta} \tag{24}$$

By equations (21), (24) the value of $\delta\theta$ may be calculated from the trigonometrical tables without further approximation.

To obtain an expansion. we have

$$\begin{aligned}\delta\theta = \sin\delta\theta &= \frac{\mu_0 \tan\theta}{1 + c/a} - \tan\theta\cos\delta\theta \\ &= \tan\theta\left\{\frac{\mu_0}{1 + c/a} - 1\tfrac{1}{2}(\delta\theta)^2\right\} \\ &= (\mu_0 - 1)\tan\theta\left\{1 - \frac{\mu_0 c}{(\mu_0 - 1)a} + \tfrac{1}{2}(\mu_0 - 1)\tan^2\theta\right\} \\ &= (\mu_0 - 1)\left(1 - \frac{l}{a}\right)\tan\theta \\ &\qquad - (\mu_0 - 1)\left(\frac{l}{a} - \frac{\mu_0 - 1}{2}\right)\tan^3\theta\end{aligned} \tag{25}$$

To this order of approximation the refraction can be expressed in terms of the condition of things at the earth's surface, and (25) is equivalent to an expression deduced at great length by Laplace.

From the value of l already quoted, and $a = 6.3709 \times 10^8$ centim., we get

$$l/a = .0012541 \tag{26}$$

If further we take as the value under standard conditions for the line D

$$\mu_0 - 1 = .0002927, \tag{27}$$

we find as the refraction expressed in seconds of arc

$$\delta\theta = 60''.29 \tan \theta - 0''.06688 \tan^3 \theta \qquad (28)$$

In (28) θ is the apparant zenith distance, and it should be understood that the application of the formula must not he pushed too close to the horizon. If the density of the air at the surface of the earth differ from the standard density (0° and 760 millim.) the numbers in (28) must be altered proportionately. It will be observed that the result has been deduced entirely *à priori* on the basis of data obtained in laboratory experiments.

It may be convenient for reference to give a few values calculated from (28) of the refraction, and of the dispersion, reckoned at $\frac{1}{40}$ of the refraction.

Apparent zenith distance.	Refraction.	Dispersion (B to H).
°	″	″
0	0.0	0.0
20	21.9	.5
40	′ 50.5	1.3
45	1 0.2	1.5
60	1 40.1	2.5
70	2 44.2	4.1
75	3 41.5	5.5
80	5 29.7	8.2
85	9 49.2	14.7

The results of the formula (28) agree with the best tables up to a zenith distance of 75°, at which point the value of the second term is 3″.5. For 85° the number usually given is 10′ 16″, and for 90° about 36′; but at these low altitudes the refraction is necessarily uncertain on account of irregularities such as those concerned in the production of mirage.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The New Telescope of the Dudley Observatory.—At the November meeting of the National Academy at Albany, Professor Hastings read a paper on a new form of telescope objective, as applied to the 12-inch equatorial of the Dudley Observatory. The objective was made by Mr. Brashear, and its novel featnres were described in the December number of this journal 1892. Professor Boss expresses much satisfaction with its performance, which he has already tested quite thoroughly. The formal opening of the new Observatory was attended by members of the Academy, and the chief address was read by Professor Newcomb.

Shadows of Jupiter's Satellites.—In No. 31 of the Publications of the Astronomical Society of the Pacific, Professor Schaeberle gives a formula for determining at any time the apparent shape of the shadow of a satellite on the surface of Jupiter. The elongated forms often observed are accounted for on simple geometrical principles. In the case of the first satellite the length of the apparent shadow may be more than twice its breadth. Anomalous outlines may be caused by differences in the brilliancy of the surface where the shadow is projected on it.

Jupiter in 1893.—The red spot on Jupiter is now extremely faint, differing so little in color and brightness from the surface in its neighborhood that it can barely be recognized. The outline is still a fairly true ellipse which is somewhat darker at the extremities of the major axis than elsewhere, the darkest place being at the following end. In a small telescope this darkening causes the spot to appear unduly elongated. The color of the spot is a very pale pink.

Interesting detail appears in the northern hemisphere, particularly in the northern equatorial belt. A series of very small black spots is seen in a latitude of about 50°.

Notes on Small Stars.—In No. 31 of the Publications of the Astronomical Society of the Pacific, there is a note by W. W. C. on a small red star DM. + 36° 4025, which is supposed not to have been observed before. DM. + 36° 4028 belongs to type II b, and should be excluded from the list of stars of type III b, in which it is placed by Scheiner.

We believe that the red star was noted some years ago by Espin.

A New Catalogue of Colored Stars.—A valuable addition to astro-physical literature is a catalogue of colored stars, with special reference to spectral types, just published at Kiel in the familiar print of the *Astronomische Nachrichten.* The catalogue, by Herr Friedrich Krüger, had its origin in an essay on colored stars which won a prize offered by the faculty of the University, and which was subsequently enlarged into its present form and printed as Vol. VIII of the Publications of the Kiel Observatory. It contains all stars north of 23° South declination which are of a yellow or reddish color, or which are remarkable through the existence of absorption bands in their spectra, and as original sources were always consulted in the compilation, and moreover as every star within reach of the Kiel 8½-inch refractor was specially examined with a spectrocsope, it embodies a large amount of research.

The introduction contains an account of previous catalogues; the work of different observers—their instruments and methods; an explanation of the different systems of stellar classification; a description of Herr Krüger's own observations and of the arrangement of the catalogue (in which the index of abbreviations is practically a bibliography of the literature of colored stars), and other matter of much interest. In the catalogue are given the number of each star, the number in the Durchmusterung and in the Birmingham catalogues, the right ascension and declination for 1900 with the amount of precession, the magnitude according to the Durchmusterung, the Harvard Photometry and the Kiel observations, the color on a scale of 0 for pure white and 10 for pure red, the type of spectrum according to Secchi's classification and in the system of the Draper Catalogue, the principal observers, and more or less extended notes. At the end is a fine lithographed plate of Secchi's spectral types, in which, however, contrary to recent usage, the red end of the spectrum is placed on the left.

Stars of Class I c (Vogel) are not included, nor are most of the Wolf-Rayet stars, although probably all the stars of the latter class are characterized by strong absorption bands which might give them claims to admission. We take pleasure in calling attention to the value of this catalogue, to which further interest is added by the novelty of spectroscopic observations in the series of Kiel Observatory publications.

The Nature of the Sun's Photosphere.—An interesting discussion of the above-mentioned subject is contained in the last two numbers of *Knowledge*, originating in some remarks made by Professor Arthur Smithells in a lecture on "Flame," delivered before the British Association at Nottingham. Professor Smithells said, "The Earth is known to be a cooling body, and also an oxidized body. At one time it must have been too hot for the oceans to have existed upon it in a liquid state, and at a still more remote period all the waters of the Earth probably existed as an enormous gaseous envelope of uncombined hydrogen and oxygen. Chemistry forces us to imagine an intervening time at which this oxygen and hydrogen would begin to combine. During that period, huge cosmical flames would rend the atmosphere. The steam formed would descend to the hotter strata of the pre-geologic atmosphere, would be dissociated and sent forth again to combine in the upper atmosphere, causing an incessant celestial pyrotechny;" hence in the opinion of the lecturer, the Earth at that remote period must have had an appearance somewhat resembling that of the Sun at the present time.

Mr. Ranyard is not able to adopt this view as to the constitution of the solar photosphere, but thinks that perhaps too little attention has been paid to the possibility of explosive chemical combinations in the Sun. Without them it is difficult to account for the violent uprushes of matter observed in the chromosphere, and the greatly extended streamers of the corona. Luminous gas would however scarcely account for the intense brilliancy of the photosphere, and we must look to incandescent solid particles as the source of its light. We are led to conclude "that the light of the photosphere must be due to the brilliant incandescence of the most refractory substances present in the Sun, at a level where they are just on the point of being driven into vapor." The solar atmosphere at the photospheric level must be excessively tenuous, but it is not necessary to assume that the condensed particles float in it as clouds of condensed water vapor float in the atmosphere of the Earth. Each particle would be retarded in its descent by the reaction produced by vaporization on the side turned toward the Sun. At a certain level which might be at a great height the particles would tend to accumulate, although other solar phenomena show that the denser parts of the Sun are not very far below the photosphere.

Miss Clerke raises the objection that if photospheric temperatures are determined by the boiling-points of the most refractory substances present, as they would be according to Mr. Ranyard's explanation, a very narrow range of diversity can be allowed to stellar emissive power, while such data as we can obtain show that the range is very great. This assumes that all stars are composed of nearly the same materials, a point which Mr. Ranyard cannot allow. The range of density may be very great. In the Hercules cluster the stars are perhaps very little denser than the streams of nebulous matter in which they are situated, and hence their density is only something like a thousand millionth part of that of the Sun.

Mr. Evershed points out that gases cooling down from a temperature above that of dissociation could not combine with explosive violence, as they are already at the temperature which represents the energy of their chemical combination. Union would follow the gradual fall of temperature, but it would be slow on that account, and no explosion would result. To this Professor Smithells replies that examples of false equilibrium are common in chemistry, and that the gases might be cooled far below the dissociation point in certain regions without combining; while he disclaims any intention to herald a new theory of the Sun, he thinks that *a priori* thermo-chemical reasoning should be used with caution, and that one must not rashly exclude chemical action as a factor in solar phenomena.

In connection with this interesting discussion we may observe that Mr. Ranyard's views as to the source of the photospheric light are quite similar to those of Professor Hastings, as set forth in his "Theory of the Constitution of the Sun," printed in the Proceedings of the American Academy, 1880. The substance which by its precipitation from the gaseous state causes the intense incandescence of the photosphere was regarded by Professor Hastings as some member of the carbon group, and most probably silicon. The theory was shown to account very satisfactorily for the sudden brightening at the inner ends of the penumbral filaments in a sun-spot.

Preliminary Note on the Spectrum of the Orion Nebula.—It has heretofore been assumed that the visible spectrum of the Orion Nebula exhibits an essential and fundamental sameness. This view differs so radically from the results of my observations that I desire to present the following preliminary note on the subject.

The relative intensities of the three principal lines vary within wide limits for the different parts of the nebula. In the dense region adjacent to the Trapezium, the intensities of the lines (wave-lengths 501, 496 and 486) are represented approximately by the ratios 4 : 1 : 1. For many regions of medium intensity the lines at 501 and 486 are about equally bright. Many of the faint portions on the south and west borders of the nebula give a spectrum in which the third line ($H\beta$ 486) is brighter than the first (501). In particular, the isolated portion north-east of the Trapezium (surrounding the star *Bond* No. 734) gives a spectrum in which the third line is at least five times as intense as the first.

The relative intensities of the first and third lines change rapidly as the slit is moved over the nebula. It often happens that of two adjacent parts in the short slit at the same time, one gives a spectrum in which the first line is stronger than the third, and the other a spectrum in which the third is stronger than the first.

The ratio of the intensities of the first and second lines remains practically constant at 4 : 1. In nearly the whole nebula the second line is fainter than the the third.

In general the hydrogen line (486) is relatively very strong in the faint outlying regions. It is relatively stronger in the Orion nebula than in any other nebula I have examined, except the planetary nebula SD. — 12° 1172.*

W. W. CAMPBELL.

Mt. Hamilton, 1893, Oct. 18.

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* This nebula was discovered and the strong $H\beta$ line noticed by Mrs. M. Fleming on the Harvard College plates. See *Astr. Nach.* No. 3049.

Electro-Magnetic Theory of the Sun's Corona.—I feel that I am called upon to make a few statements bearing upon Dr. Hermann Ebert's paper, "Electro Magnetic Theory of the Sun's Corona," which appeared in the November number of ASTRONOMY AND ASTRO-PHYSICS.

An electrical theory of the Sun's corona was suggested to my mind by my experiments on electrical discharges through poor vacua (*Amer. Jour. Sc.*, April, 1892, p. 266) and on coronoidal discharges (*Amer. Jour. Sc.*, (3) 43, p. 463, 1892; ASTRONOMY AND ASTRO-PHYSICS, May, 1892, paper read before the National Academy of Sciences, Washington, April 22nd, 1892, and I did not hesitate to express my belief in the scientific value of this theory; in fact, I was so fascinated by it that I put myself considerably out of the way to arrange my experiments on electrical discharges in such a way as to bring out forcibly the resemblance between these discharges and the solar corona.

Subsequent experiments, which I did not publish, encouraged me more and more to consider seriously the Electrical Theory of the Solar Corona, and at the request of Professor J. K. Rees, of Columbia College, I read a paper, on Dec. 5th, 1892, before the New York Academy of Sciences, on the Electro Magnetic Theory of the Solar Corona. This paper I abstracted for the Transactions of the Academy; a reference to it and the electro-magnetic theory it contains was made in a letter which I addressed to the Editor of ASTRO-PHYSICS and was published in your esteemed journal, May, 1893.

A comparison of Dr. Ebert's theory and mine will show that they are identical. Dr. Ebert's reference to my experimental investigations in this matter seems to indicate that he claims the priority of suggesting this theory, or, at any rate, the priority of experimenting upon such electrical discharges through gases which would tend to support this theory. So far as I can see, he has no ground on which he could support this claim, if he really makes it at all. For, in the first place I was very much ahead of him in point of time of publication; in the second place I commenced my experimental investigations early in 1891 (see *Amer. Jour. Sc.*, June, 1892, p. 465), and Dr. Ebert, according to his own statement in the paper mentioned above, did not commence any sooner.

M. I. PUPIN.

Columbia College, New York, Nov. 21, 1893.

New Variables.—Mrs. Fleming has detected a new variable star on the Harvard plates in R. A. $15^h 22^m 16^s$, Dec. — 50° 14′. Its magnitude on July 10 was 7.0.

According to a Wolsingham circular, an anonymous red star in R. A. $20^h 46' 59^s$, Dec. + 46° 47′, is variable. It was of the 9.1 magnitude on Aug. 21, and is now fading. (This star is not in the new catalogue of Krüger, which is mentioned in another note.)

Professor W. H. Pickering is now at Cambridge, Mass. He will, for some time to come, be occupied in preparing the observations made at Arequipa, South America for publication.

G. W. Hanchett, Hyde Park, Mass., is fitting up a small Observatory and is about to order a 6½-inch telescope. His attention will be given largely to observation of double stars.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR JANUARY.

Mercury having been at greatest western elongation Dec. 14 will in January be too close to the Sun for observation. He will be at superior conjunction Jan. 29 at 6^h 36^m A. M.

Venus which has been such a brilliant object in the early evening sky during the past month will be still more brilliant during the first part of January. This planet will attain its maximum brilliancy on Jan. 10 when the light will be 218 as compared with 145 on December 1. The position of Venus is becoming a little more favorable for observation in northern latitudes, as the planet moves northward in declination. Venus and the crescent Moon will be in conjunction on the morning of Jan. 10 and the two will form a pretty pair on that evening and the preceding.

Mars will be morning planet during January, visible in the southeast after five o'clock. The low altitude will prevent good observations in our latitude, but south of the equator something may be done in the study of the surface markings of the planet. Mars and the waning Moon will be in conjunction on the morning of Jan. 3, the latter passing 4° south of the former.

Jupiter will be in excellent position for observation during the first half of the night in January. The planet will be stationary among the stars of Taurus on Jan. 15, after which it will move slowly eastward. The "great red spot" was well seen by us with the 16-inch telescope on the night of Oct. 31. Its centre was on the central meridian of Jupiter at 11^h 31^m, Central time, as near as we could estimate. This time agrees closely with that predicted by Mr. Marth. The spot was seen without difficulty although the color was quite faint. The color was exactly the same as that of the belt just to the south of it, and the two objects merged into one another without the slightest change in intensity of color. The outline of the spot seems to be the same as in past years, except as stated above, that its southern edge is merged into the belt. There seemed to be two white clouds over the central portions of the spot, the following of the two being the larger. The seeing was excellent during this observation and much of very minute detail was seen in all the belts.

Saturn is getting into better position for observation in the morning but the majority of observers will prefer to wait two or three months until the planet is visible in the evening. Saturn will be at quadrature, 90° west from the Sun, Jan. 14. Saturn is in the constellation Virgo a little northeast of Spica and is moving very slowly eastward. The Moon will be 4° south of Saturn at noon Jan. 27.

Uranus is in the constellation Libra a little way east of the star α. It is not yet in very good condition for observation in our latitude.

Neptune having passed opposition in December will be in excellent position for observation in January. It will move very slowly westward during the month, the position January 1 being a little more than ⅓ of the distance on a straight line from ι to ε Tauri. There is no star of equal brightness within a radius of 1°.

PLANET TABLES FOR JANUARY.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

Date. 1894.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MERCURY.		
Jan. 5	18 06.0	− 24 00	6 44 A. M.	11 04.9 A. M.	3 25 P. M.
15	19 14.0	− 23 53	7 12 “	11 33.3 “	3 54 “
25	20 24.1	− 21 26	7 31 “	12 04.0 P. M.	4 37 “
			VENUS.		
Jan. 5	22 01.3	− 11 39	9 43 A. M.	2 59.5 P. M.	8 16 P. M.
15	22 18.6	− 8 06	9 06 “	2 37.6 “	8 09 “
25	22 23.6	− 5 16	8 21 “	2 03.2 “	7 46 “
			MARS.		
Jan. 5	16 04.4	− 20 33	4 26 A. M.	9 03.6 A. M.	1 41 P. M.
15	16 33.2	− 21 49	4 22 “	8 53.0 “	1 24 “
25	17 02.6	− 22 47	4 16 “	8 43.0 “	1 10 “
			JUPITER.		
Jan. 5	3 17.6	+ 17 16	1 00 P. M.	8 15.0 P. M.	3 30 A. M.
15	3 17.0	+ 17 16	12 20 “	7 35.0 “	2 50 “
25	3 17.7	+ 17 22	11 41 A. M.	6 56.3 “	2 12 “
			SATURN.		
Jan. 5	13 34.3	− 7 12	12 59 A. M.	6 33.8 A. M.	12 09 P. M.
15	13 35.8	− 7 19	12 22 “	5 56.1 “	11 30 A. M.
25	13 36.8	− 7 21	11 43 P. M.	5 17.7 “	10 52 “
			URANUS.		
Jan. 5	14 48.6	− 15 49	2 49 A. M.	7 48.1 A. M.	12 47 P. M.
15	14 49.9	− 15 55	2 12 “	7 10.1 “	12 09 “
25	14 51.0	− 15 59	1 33 “	6 31.8 “	11 30 A. M.
			NEPTUNE.		
Jan. 5	4 39.8	+ 20 36	2 04 P. M.	9 36.9 P. M.	5 09 A. M.
15	4 39.0	+ 20 35	1 24 “	8 56.8 “	4 29 “
25	4 38.3	+ 20 34	12 41 “	8 16.8 “	3 59 “
			THE SUN.		
Jan. 5	19 07.1	− 22 34	7 38 A. M.	12 05.8 P. M.	4 34 P. M.
15	19 50.5	− 21 02	7 35 “	12 09.8 “	4 45 “
25	20 32.8	− 18 50	7 27 “	12 12.6 “	4 58 “

Phases and Aspects of the Moon.

		d	*Central Time.* h m
Apogee	Jan.	5	6 00 A. M.
New Moon	“	6	9 07 P. M.
First Quarter	“	14	6 09 P. M.
Perigee	“	20	9 12 A. M.
Full Moon	“	21	9 12 A. M.
Last Quarter	“	28	10 51 A. M.

Occultations Visible at Washington.

Date 1894.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt. °	Duration. h m
Jan. 11	χ Aquarii	5½	6 52	89	7 48	198	0 56
18	136 Tauri	5	16 16	105	17 05	266	0 49
19	W. VI, 1656	8	17 08	140	17 48	247	0 40
20	e Geminorum	6	4 49	110	5 38	254	0 49
20	ω^1 Cancri	6	12 19	83	13 25	319	1 06
20	ω^2 Cancri	6	12 54	129	14 04	273	1 10

Phenomena of Jupiter's Satellites.

Central Time.

		h	m			
Jan.	5	12	07	A. M.	II	Tr. In.
		12	18	"	I	Tr. In.
		1	22	"	I	Sh. In.
		2	13	"	II	Sh. In.
		2	28	"	II	Tr. Eg.
		2	30	"	I	Tr. Eg.
		3	34	"	I	Sh. Eg.
		9	32	P. M.	I	Oc. Dis.
	6	12	47	A. M.	I	Ec. Re.
		6	38	P. M.	II	Oc. Dis.
		6	46	"	I	Tr. In.
		6	48	"	III	Oc. Dis.
		7	51	"	I	Sh. In.
		8	37	"	III	Oc. Re.
		9	58	"	I	Tr. Eg.
		10	03	"	I	Sh. Eg.
		11	05	"	II	Ec. Re.
		11	18	"	III	Ec. Dis.
	7	12	57	A. M.	III	Ec. Re.
		4	00	P. M.	I	Oc. Dis.
		7	16	"	I	Ec. Re.
	8	4	32	"	I	Sh. Eg.
		5	54	"	II	Sh. Eg.
	12	11	23	"	I	Oc. Dis.
	13	2	43	A. M.	I	Ec. Re.
		8	35	P. M.	I	Tr. In.
		9	03	"	II	Oc. Dis.
		9	46	"	I	Sh. In.
		10	27	"	III	Oc. Dis.
		10	48	"	I	Tr. Eg.
		11	25	"	II	Oc. Re.
		11	26	"	II	Ec. Dis.
		11	58	"	I	Sh. Eg.
	14	12	19	A. M.	III	Oc. Re.
		1	41	"	II	Ec. Re.
		5	50	P. M.	I	Oc. Dis.
		9	12	"	I	Ec. Re.
	15	3	03	"	I	Tr. In.
		3	49	"	II	Tr. In.
		4	14	"	I	Sh. In.
		5	15	"	I	Tr. Eg.
		6	11	"	II	Tr. Eg.
		6	11	"	II	Sh. In.
Jan.	15	6	27	P. M.	I	Sh. Eg.
		8	33	"	II	Sh. Eg.
	17	5	22	P. M.	III	Sh. In.
		7	15	"	III	Sh. Eg.
	20	10	26	"	I	Tr. In.
		11	30	"	II	Oc. Dis.
		11	41	"	I	Sh. In.
	21	12	39	A. M.	I	Tr. Eg.
		7	42	P. M.	I	Oc. Dis.
		11	08	"	I	Ec. Re.
	22	4	54	"	I	Tr. In.
		6	10	"	I	Sh. In.
		6	21	"	II	Tr. In.
		7	07	"	I	Tr. Eg.
		8	22	"	I	Sh. Eg.
		8	43	"	II	Tr. Eg.
		8	50	"	II	Sh. In.
		11	12	"	II	Sh. Eg.
	23	5	37	"	I	Ec. Re.
	24	5	35	"	II	Ec. Re.
		6	09	"	III	Tr. Eg.
		9	24	"	III	Sh. In.
		11	18	"	III	Sh. Eg.
	28	12	19	A. M.	I	Tr. In..
		1	36	"	I	Sh. In.
		2	00	"	II	Oc. Dis.
		9	35	P. M.	I	Oc. Dis.
	29	1	04	A. M.	I	Ec. Re.
		6	47	P. M.	I	Tr. In.
		8	05	"	I	Sh. In.
		8	54	"	II	Tr. In.
		8	59	"	I	Tr. Eg.
		10	18	"	I	Sh. Eg.
		11	17	"	II	Tr. Eg.
		11	29	"	II	Sh. In.
	30	1	50	A. M.	II	Sh. Eg.
		4	04	P. M.	I	Oc. Dis.
		7	33	"	I	Ec. Re.
	31	5	39	"	II	Oc. Re.
		5	55	"	II	Ec. Dis.
		8	03	"	III	Tr. In.
		9	11	"	II	Ec. Re.
		10	03	"	III	Tr. Eg.

Configuration of Jupiter's Satellites at 9^h Central Time, for an Inverting Telescope.

Jan.	
1	2 1 ○ 3 4
2	2 ○ 3 1 4
3	3 1 ○ 2 4
4	3 4 ○ 2 1
5	3 4 2 1 ○
6	4 1 ○ 3 ●
7	4 ○ 1 2 3
8	4 1 2 ○ 3
9	4 2 ○ 3 1
10	4 3 1 ○ 2
11	3 4 ○ 2 1
12	3 2 4 1 ○
13	♃ 3 ○ 4 ●
14	● ○ 2 3 4
15	1 2 ○ 3 4
16	2 ○ 1 3 4
17	1 3 ○ 2 4
18	3 ○ 1 2 4
19	3 2 1 ○ 4
20	3 2 ○ 1 4
21	4 ○ 3 2 ●
22	4 1 2 ○ 3
23	4 2 ○ 1 3
24	4 1 3 ○ 2
25	4 3 ○ 1 2
26	4 3 2 1 ○
27	4 3 2 ○ 1
28	4 1 ○ 3 2
29	♃ 1 4 ○ 3
30	2 ○ 1 4 3
31	♃ 1 ○ 2 4

Approximate Times when the Great Red Spot will pass the Central Meridian of Jupiter.

		h m		h m		h m
Jan.	2	12 40 A. M.	12	6 48 P. M.	22	5 06 P. M.
	2	8 31 P. M.	14	12 36 A. M.	23	10 58 "
	3	4 23 "	14	8 27 P. M.	24	6 45 "
	4	10 10 "	15	5 18 "	26	12 31 A. M.
	5	6 01 "	16	10 06 "	26	8 24 P. M.
	6	11 48 "	17	5 57 "	27	4 15 "
	7	7 40 "	18	11 44 "	28	10 02 "
	9	1 27 A. M.	19	7 36 "	29	5 54 "
	9	9 18 P. M.	21	1 22 A. M.	30	11 41 "
	10	5 10 "	21	9 14 P. M.	31	7 33 "
	11	10 57 "				

Ephemeris of the Fifth Satellite of Jupiter.

Approximate Central Times of Greatest Elongations.

		Eastern Elongation.	Western Elongation.			Eastern Elongation.	Western Elongation.
Jan.	1	9 39 P. M.	3 38 A. M.	Jan.	17	8 16 P. M.	2 15 A. M.
	3	9 29 "	3 28 "		19	8 06 "	2 05 "
	5	9 18 "	3 17 "		21	7 55 "	1 54 "
	7	9 08 "	3 07 "		23	7 45 "	1 44 "
	9	8 57 "	2 56 "		25	7 35 "	1 34 "
	11	8 47 "	2 46 "		27	7 25 "	1 24 "
	13	8 37 "	2 36 "		29	7 15 "	1 14 "
	15	8 26 "	2 25 "		31	7 05 "	1 04 "

Elongations of the Satellites of Saturn.

(The western elongations will be found approximately half way between the eastern and other positions may be easily interpolated.)

MIMAS.

		h		
Jan.	2	5.7	A. M.	W
	3	4.3	"	W
	4	2.9	"	W
	9	7.3	"	E
	10	6.0	"	E
	11	4.6	"	E
	12	3.2	"	E
	13	1.8	"	E
	17	7.6	"	W
	18	6.2	"	W
	19	4.9	"	W
	20	3.5	"	W
	21	2.1	"	W
	25	7.9	"	E
	26	6.5	"	E
	27	5.1	"	E
	28	3.7	"	E
	29	2.3	"	E

ENCELADUS.

Jan.	2	2.2	A. M.	E
	3	11.9	"	E
	4	7.9	P. M.	E
	6	4.8	A. M.	E
	7	1.7	P. M.	E
	8	10.6	"	E
	10	7.5	A. M.	E
	11	4.3	P. M.	E
	13	1.2	A. M.	E
	14	10.1	"	E
	15	7.0	P. M.	E
	17	3.9	A. M.	E
	18	12.7	P. M.	E
	19	9.6	P. M.	E

ENCELADUS CONT.

		h		
Jan.	21	6.5	A. M.	E
	22	3.4	P. M.	E
	24	12.3	A. M.	E
	25	9.1	"	E
	26	6.0	P. M.	E
	28	2.9	A. M.	E
	29	11.8	"	E
	30	8.7	P. M.	E
Feb.	1	5.5	A. M.	E

TETHYS.

Jan.	2	11.7	P. M.	E
	4	9.0	"	E
	6	6.3	"	E
	8	3.6	"	E
	10	12.9	"	E
	12	10.2	A. M.	E
	14	7.5	"	E
	16	4.8	"	E
	18	2.1	"	E
	19	11.4	P. M.	E
	21	8.7	"	E
	23	6.0	"	E
	25	3.3	"	E
	27	12.6	"	E
	29	9.9	A. M.	E
	31	7.2	"	E

DIONE.

Jan.	2	12.7	P. M.	E
	5	6.3	A. M.	E
	7	midn.		E
	10	5.7	A. M.	E
	13	11.4	A. M.	E

DIONE CONT.

		h		
Jan.	16	5.0	"	E
	18	10.7	P. M.	E
	21	4.4	"	E
	24	10.1	A. M.	E
	27	3.7	"	E
	29	9.4	P. M.	E

RHEA.

Jan.	2	5.0	P. M.	E
	7	5.4	A. M.	E
	11	5.9	P. M.	E
	16	6.1	A. M.	E
	20	6.5	P. M.	E
	25	6.9	A. M.	E
	29	7.3	P. M.	E

TITAN

Jan.	3	8.2	P. M.	S
	7	3.5	"	E
	11	1.2	"	S
	15	5.0	"	W
	19	7.1	"	S
	23	2.3	"	E
	27	noon		I
	31	3.6	"	W

HYPERION.

Jan.	6	3.9	A. M.	E
	12	12.1	P. M.	I
	17	8.5	"	W
	22	6.3	A. M.	S
	27	10.1	"	E

IAPETUS.

Jan.	20	4.3	P. M.	E
Feb.	7	10.5	"	I

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

R. A.................$0^{h}\ 52^{m}\ 32^{s}$
Decl.................$+81^{\circ}\ 17'$
Period...........$2d\ 11^{h}\ 50^{m}$

Jan.	5	1 A. M.
	9	midn.
	14	“
	19	“
	24	11 P. M.
	29	11 “

ALGOL.

R. A...............$3^{h}\ 1^{m}\ 1^{s}$
Decl.................$+42^{\circ}\ 32'$
Period...........$2d\ 20^{h}\ 49^{m}$

Jan.	2	2 A. M.
	4	11 P. M.
	7	8 “
	10	5 “
	22	4 A. M.
	25	1 “
	27	10 P. M.
	30	7 “

R. CANIS MAJORIS.

R. A.............. $7^{h}\ 14^{m}\ 30^{s}$
Decl..............$-16^{\circ}\ 11'$
Period.........$1d\ 3^{h}\ 16^{m}$

Jan.	1	9 P. M.
	2	midn.
	4	3 A. M.
	9	7 P. M.
	10	11 “
	12	2 A. M.
	13	5 “
	17	6 P. M.
	18	10 “
	20	1 A. M.
	21	4 “
	26	8 P. M.

R. CANIS MAJ. CONT.

Jan.	27	midn.
	29	3 A. M.
	30	6 “

S CANCRI.

R. A.............. $8^{h}\ 37^{m}\ 39^{s}$
Decl................$+19^{\circ}\ 26'$
Period............$9d\ 11^{h}\ 38^{m}$

Jan.	7	4 P. M.
	17	3 A. M.
	26	3 P. M.

S ANTLIÆ.

R. A.............. $9^{h}\ 27^{m}\ 30^{s}$
Decl..............$-28^{\circ}\ 09'$
Period.......... $0d\ 7^{h}\ 27^{m}$

Jan.	1	2 A. M.
	2	1 “
	2	midn.
	3	“
	4	11 P. M.
	5	10 “
	6	10 “
	7	9 “
	8	5 A. M.
		8 P. M.
	9	4 A. M.
		8 P. M.
	10	4 A. M.
		7 P. M.
	11	3 A. M.
	12	2 “
	13	2 “
	14	1 “
	14	midn.
	15	“
	16	11 P. M.
	17	10 “

S. ANTLIÆ CONT.

Jan.	18	10 P. M.
	19	5 A. M.
		9 P. M.
	20	5 A. M.
		8 P. M.
	21	4 A. M.
		8 P. M.
	22	3 A. M.
	23	3 “
	24	2 “
	25	1 “
	26	1 “
	26	midn.
	27	11 P. M.
	28	11 “
	29	10 “
	30	9 “
	31	9 “

δ LIBRÆ.

R. A.......... ..$14^{h}\ 55^{m}\ 06^{s}$
Decl............... $-\ 8^{\circ}\ 05'$
Period.......... $2d\ 07^{h}\ 51^{m}$

Jan.	2	1 A. M.
	9	1 “
	15	midn.
	22	“
	29	11 P. M.

U. CORONÆ.

R. A ....$15^{h}\ 13^{m}\ 43^{s}$
Decl............... $+32^{\circ}\ 03'$
Period.......... $3d\ 10^{h}\ 51^{m}$

Jan.	11	7 A. M.
	18	4 “
	24	2 “
	31	midn.

Numeration of the Asteroids discovered in 1893.—Numbers have recently been assigned to twenty-one of the asteroids discovered by photography this year. Seven others designated 1893 C, D, M, O, U, X, and Y, were not sufficiently observed to permit of determining their elliptic orbits. They therefore receive no numbers. The asteroid 1893 Q has been found to be identical with (104) Klymene, Z with (175) Andromache, AF with (158) Koronis, and AG with (107) Camilla.

The numbers assigned are as follows:

1893	A	Jan.	17	Charlois	354
	B		12	Wolf	352
	E		20	Charlois	356
	F		16	Wolf	353
	G		21	Charlois	355
	J	Feb.	11	“	357
	K	Mar.	8	“	358
	L		9	“	359
	N		11	“	360
	P		11	“	361
	R		17	“	362

1893	S	Mar.	17	Charlois	363
	T		19	“	364
	V		21	“	365
	W		21	“	366
	AA	May	20	“	367
	AB		20	“	368
	AC	July	14	“	370
	AD		16	“	371
	AE		5	Borrelly	369
	AH	Aug.	19	Charlois	372

COMET NOTES.

Comet 1893 II (*b* 1893).—This comet was observed with the 16-inch equatorial at Goodsell Observatory on the morning of Nov. 18. It was very close to the place indicated by Cerulli's ephemeris, published in our last number. It was very faint, about 1′ in diameter, with a slight condensation in the center, so that a fairly good measure could be taken of its position. From. *Astr. Jour.* No. 307 we take the following ephemeris for December:

Gr. M. T.	App. R. A.			Decl.				Log Δ	Br.
	h	m	s		°	′	″		
Dec. 5.5	12	44	32.1	−	0	08	37		
6.5		44	13.3		0	07	59		
7.5		44	55.9		0	07	13	0.4594	0.078
8.5		43	33.0		0	06	19		
9.5		43	10.8		0	05	16		
10.5		42	47.3		0	04	04		
11.5		42	22.5		0	02	44	0.4554	0.077
12.5		41	56.4	−	0	01	16		
13.5		41	28.9	+	0	00	22		
14.5		41	00.0		0	02	08		
15.5		40	29.8		0	04	03	0.4511	0.076
16.5		39	58.2		0	06	07		
17.5		39	25.1		0	08	21		
18.5		38	50.5		0	10	43		
19.5		38	14.5		0	13	15	0.4465	0.074
20.5		37	37.0		0	15	56		
21.5		36	58.0		0	18	47		
22.5		36	17.5		0	21	48		
23.5		35	35.4		0	24	58	0.4417	0.073
24.5		34	51.8		0	28	17		
25.5		34	06.6		0	31	47		
26.5		33	19.8		0	35	27		
27.5		32	31.3		0	39	16	0.4367	0.072
28.5		31	41.2		0	43	15		
29.5		30	49.4		0	47	25		
30.5		29	56.0		0	51	45		
31.5	12	29	01.0	+	0	56	15	0.4317	0.072

Perturbations and Ephemeris of Comet Holmes.—This body will be in opposition on Jan. 18, 1894, and will be soon in a position favorable for observation. It should be easily found provided its appearance be anything like that which it presented for a considerable time after its discovery, but if, as is quite possible, it has assumed the guise of an *asteroid* of small dimensions, the search for it may be a matter of some difficulty if pursued by the ordinary visual means. A search ephemeris should include the effects of the perturbative action of the planet Jupiter, which action has been very sensible during the time which has elapsed since the date of Holmes' discovery of this remarkable body. I have therefore computed the *special* perturbations of the elliptic elements of the orbit of this body for the dates given in the first column of the following table. I have adopted as the elements osculating at the epoch, those computed by Mr. J. R. Hind, and published in *Astr. Nach.* No. 3152. They are the following:

1892, Nov. 9.5 Gr. M. T.

$$\left.\begin{array}{rl} M_0 = & 21^\circ\ 12'\ 43''.5 \\ \pi_0 = & 346^\circ\ 16'\ 04''.7 \\ \Omega_0 = & 331^\circ\ 35'\ 38''.2 \\ i_0 = & 20^\circ\ 46'\ 46''.4 \\ \varphi_0 = & 24^\circ\ 06'\ 16''.1 \\ \mu_0 = & 513''.90765 \\ \log a_0 = & 0.5594143 \end{array}\right\} 1892.0$$

By means of these elements I have computed the following perturbations thereof:

Date.			δ☊	δi	$\delta\pi$	$\delta\varphi$	$\delta\mu$	δM
			″	″	″	″	″	″
1892	Nov.	29.5	− 11.32	− 1.56	− 27.90	− 4.10	+ 0.04748	+ 21.74
1893	Jan.	8.5	34.04	3.44	86.82	14.42	0.16094	68.12
	Feb.	17.5	55.40	3.84	146.49	25.52	0.28352	126.34
	Mch.	29.5	74.42	3.15	203.75	35.92	0.40289	193.07
	May	8.5	90.81	− 1.70	256.96	45.10	0.51312	265.57
	June	17.5	104.68	+ 0.19	305.70	53.03	0.61244	342.03
	July	27.5	116.29	2.35	350.18	59.85	0.70118	421.39
	Sept.	5.5	125.95	4.63	390.92	65.77	0.78018	503.11
	Oct.	15.5	133.98	6.93	428.58	70.94	0.85082	586.98
	Nov.	24.5	140.65	9.21	463.81	75.50	0.91441	672.98
1894	Jan.	3.5	146.21	11.45	497.21	79.50	0.97207	761.17
	Feb.	12.5	150.88	13.65	529.31	83.00	1.02483	851.65
	Mch.	24.5	154.82	15.80	560.58	85.97	1.07357	944.55
	May	3.5	− 158.14	+ 17.92	− 591.28	− 88.42	+ 1.11882	+ 1039.89

Interpolating for 1894, Jan. 1.0, I have found the perturbations for that date to be: δ☊, − 2′ 25″.97; δi, + 11″.31; $\delta\pi$, − 8′ 15″.16; $\delta\varphi$, − 1′ 19″.27; $\delta\mu$, + 0″.96861; δM, + 12′ 35″.73. Adding these to the fundamental osculating elements above given, and reducing to the mean equinox of 1894.0, I have obtained the following system:

1894, Jan. 1.0 Gr. M. T.

$$\left.\begin{aligned} M &= 81^\circ\ 01'\ 15''.67 \\ \pi &= 346^\circ\ 09'\ 30''.00 \\ ☊ &= 331^\circ\ 34'\ 53''.62 \\ i &= 20^\circ\ 46'\ 58''.63 \\ \varphi &= 24^\circ\ 04'\ 56''.83 \\ \mu &= 514''.87626 \\ \log a &= 0.5588691 \end{aligned}\right\}\ 1894.0$$

The equations for the heliocentric rectangular co-ordinates are:

$$x = [9.9937180]\, r \sin(v + 77^\circ\ 44'\ 30''.2)$$
$$y = [9.8766095]\, r \sin(v + 339^\circ\ 07'\ 21''.8)$$
$$z = [9.8323171]\, r \sin(v + 358^\circ\ 23'\ 46''.2)$$

From the data above given I have computed the following ephemeris, the places being referred to the mean equinox of 1894.0:

Greenwich M. T.			R. A.			Decl.			Log r.	Log Δ
			h	m	s	°	′	″		
1894	Jan.	1.5	8	18	40.1	+ 37	07	12.8	0.599202	0.484865
		3.5		16	48.3		10	02.5		
		5.5		14	54.0		12	25.6		
		7.5		12	57.9		14	24.1	0.601326	0.484687
		9.5		11	00.2		15	55.4		
		11.5		09	01.6		16	58.7		
		13.5		07	02.0		17	32.9	0.603426	0.485902
		15.5		05	02.2		17	37.8		
		17.5		03	02.6		17	12.0		
		19.5	8	01	03.7		16	15.6	0.605497	0.488865
		21.5	7	59	05.6		14	48.6		
		23.5		57	08.8		12	51.1		
		25.5		55	13.8		10	23.5	0.607540	0.493189
		27.5		53	20.9		07	25.8		
		29.5		51	30.4		03	58.9		
		31.5		49	42.6		00	02.9	0.609557	0.499118
	Feb.	2.5	7	47	57.9	+ 36	55	39.1		

The appearance of this comet will be of interest. Should it be in the similitude of an asteroid of about 12-13 mag. at the time of opposition, it will be reasonable to conclude that it is one of the group of " Minor Planets," and that the truth of the "asteroid collision" hypothesis concerning the origin of this peculiar body is established; but if, on the other hand, it should appear to be of considerable dimensions, or should display the ordinary *indicia* of a comet, viz., a coma and a *tail*, we should rightly adjudge the above mentioned hypothesis to be scientifically untenable.

SEVERINUS J. CORRIGAN.

St. Paul, Minnesota, Nov. 18, 1893.

Elements and Ephemeris of Comet *c* 1893.—I send you herewith elements and ephemeris of Comet *c* by Mr. Phillips Isham and myself.

$$T = \text{Sept. } 19.3055 \text{ Berlin M. T.}$$

$$\left.\begin{array}{l} \Omega = 174^\circ \;\; 54' \;\; 21'' \\ i = 129 \;\;\; 47 \;\;\; 44 \\ \omega = 347 \;\;\; 33 \;\;\; 10 \end{array}\right\} 1893.0$$

$$\log q = 9.91033$$

Berlin midn.		α app.			δ app.			log Δ
		h	m	s		°	′	
Dec.	1.5	14	03	53	+	53	15.1	0.119
	2.5		08	27		54	23.9	
	3.5		13	15		55	32.7	0.118
	4.5		18	21		56	41.4	
	5.5		23	44		57	50.0	0.117
	6.5		29	25		58	58.4	
	7.5		35	25		60	06.2	0.118
	8.5		41	48		61	13.2	
	9.5		48	35		62	19.4	0.119
	10.5		55	50		63	24.8	
	11.5	15	03	33		64	28.8	0.120
	12.5		11	48		05	31.0	
	13.5		20	36		66	31.9	0.122
	14.5		29	59		67	31.7	
	15.5		40	03		68	29.0	0.125
	16.5		50	52		69	23.4	
	17.5	16	02	26		70	15.3	0.130
	18.5		14	47		71	04.4	
	19.5		27	57		71	50.2	0.136
	20.5		41	59		72	32.4	
	21.5		56	50		73	10.7	0.143
	22.5	17	12	30		73	45.0	
	23.5		28	57		74	14.9	0.149
	24.5		46	06		74	40.2	
	25.5	18	03	43		75	00.5	0.156
	26.5		21	34		75	16.1	
	27.5		39	38		75	26.5	0.164
	28.5		57	53		75	32.5	
	29.5	19	15	53		75	33.8	0.172
	30.5		33	28		75	30.7	
	31.5		50	33	+	75	23.3	0.181

J. G. PORTER.

Comet Brooks (*c* 1893).—This comet, discovered by the writer on Oct. 16, has been observed on every possible occasion, and we have been favored with an unusually fine autumn in this locality—unusual in the great number of clear days and nights. Although the comet had passed perihelion at the time of discovery, it has held its light well, and has been a conspicuous telescopic comet. On the morning of Oct. 21, 17^h, the comet appeared brighter than at any previous observation. The tail could be easily traced to a distance of 3¼°.

Some interesting changes have been noticed in the shape and structure of the tail. Its normal appearance might have been called straight, but on the morning of Oct. 21, 17^h (when the comet appeared at its brightest here), there was a sharp curve in the tail close to the head towards the south, and a faint secondary tail was seen issuing from the head at an angle of 30° to the main tail towards the north.

Bright moonlight then interfered for several days, but when the comet was seen again, on Nov. 4, its tail had assumed its usual straight form with only slight curvature towards the extreme end. On Nov. 9, 17^h, however, another decided and interesting change was detected in the formation of the tail. It was straight for a length of half a degree from the head, where it became forked, the larger portion curving gracefully to the south, the fainter part straight or nearly so, branching to the north, the two branches making an angle with each other of about 25°. The comet on this occasion was bespangled with numerous small stars, forming altogether a most charming telescopic picture.

WILLIAM R. BROOKS.

Smith Observatory, Geneva, N. Y., Nov. 14, 1893.

Photographs of Brooks' Comet.—This comet, which never became visible to the naked eye, and which promised so little in the telescope, has proved to be photographically one of the most remarkable comets yet observed.

I have fortunately secured a splendid series of photographs of the comet on fifteen nights with the Willard lens (6 in. aperture, 31 in. focus).

The exposures have ranged from 30 minutes, at first when the comet was near the horizon, to 185 minutes in the later observations.

Following are the dates of these pictures:

Oct. 18, 20, 21, 22, Nov. 2, 3, 6, 7, 10, 11, 12, 13, 14, 15, 19. On Nov. 15, two negatives were secured each with 90 minutes exposure, to detect any extra rapid changes in the tail.

Though the tail with the 12 in. at its brightest could scarcely be traced 2° the photographs on several occasions showed it for fully 10°—and this at a time when the 12-in. could not trace it 1°.

Besides showing undoubtedly an encounter of the tail on Oct. 21st with some outside and obstructing medium in which the tail was badly shattered, the plates have several times shown independent cometary masses near the extremity of the tail, and one of these at least, I think, can be located accurately enough to determine its orbit.

Rapid and remarkable changes in position angle of the tail are also recorded on these plates.

On several of these dates meteors have left trails on the photographs with the comet, and on the morning of Nov. 14th a magnificent meteor shot across the plate parallel with the comet's tail, leaving a heavy straight trail extremely dense and sharp.

The investigation of these photographs will give us a far better insight into the phenomena of comet tails than we have ever had before.

I hope to be able soon to present some of these remarkable photographs in ASTRONOMY AND ASTRO-PHYSICS.

E. E. BARNARD.

Mt. Hamilton, Cal., Nov. 19, 1893.

The November Meteors.—The Leonid meteor radiant was photographed on the mornings of Nov. 14 and 16, with the 2½-inch Darlot lenses of Goodsell Observatory. Two exposures were made on the morning of the 14th, the one from 3^h 50^m to 5^h, the other from 5^h to 6^h. The field covered by the plates is 24° in diameter, ζ Leonis being placed in the center. The first plate on the 14th shows one meteor trail near the star κ Leonis. It is about 1° long and points exactly toward the Leonid radiant. It is near the edge of the plate where the definition is poor, so that it is not well shown. The other plates show no trails at all. I saw but few meteors while the exposures were being made, and no very bright ones. The few Leonids I did see moved so swiftly that it is doubtful whether their trails would have been impressed upon the plate had they been within the range of the camera.

H. C. W.

November Meteors.—The November meteors were far more abundant this year than I have ever seen them before. Especially were they plentiful on the mornings of November 13, 14, and 15. Many very brilliant ones were seen. One on the morning of the 14th burst just below Coma Berenices. It was nearly as large as the full Moon. On November 15th at 14^h 50^m a splendid meteor from Leo shot across the sky and burst between Zeta and Eta Ursæ Majoris. This left a persistent train about 10° long which remained bright and straight for about five minutes—like a slender comet—it then collected into a cloudy mass at the point of explosion. This elongated mass of luminosity remained distinctly visible for half an hour, drifting due east in the meantime about 7°. As I was photographing the comet at this time I could not turn my telescope to it to see how long it remained visible after it had ceased to be seen with the naked eye.

Mt. Hamilton, Nov. 19, 1893. E. E. BARNARD.

NEWS AND NOTES.

George A. Hill, United States Naval Observatory, Washington, D. C., has been appointed to the position of assistant astronomer in the Observatory. He is now at work with the Prime Vertical Transit instrument. He takes the place of A. Hall, Jr., who resigned not long ago to accept the position of director of the Detroit Observatory at Ann Arbor, Michigan.

Professor S. W. Burnham.—At a recent meeting of the Board of Trustees of the University of Chicago, Mr. S. W. Burnham was unanimously elected Professor of Practical Astronomy. The Department of Astronomy is to be congratulated on securing Professor Burnham's eminent services, and the honor which the University authorities have thus done to the cause of Science will be fully appreciated by astronomers everywhere, who will rejoice to learn that Professor Burnham will again have adequate opportunities for continuing his splendid investigations in Double Star Astronomy. It is understood that the micrometrical measurement of Double Stars is one of the principal lines of research contemplated with the great 40-inch refractor of the Yerkes Observatory.

A. G. Winterhalter of the Naval Observatory, Washington, D. C., has our thanks for a corrected copy of the paper read by Dr. Leman of Berlin at the Astronomical Congress in Chicago. It is a very useful paper.

Mr. Tebbutt's Observatory, New South Wales.—We have been favored with a copy of the report of Mr. Tebbutt's Observatory, the peninsula Windsor, New South Wales, Australia, for the year 1892.

The position of this Observatory as noticed in this report is,

Longitude = $10^h\ 3^m\ 20.51^s$ East of Greenwich,
Latitude = − 33° 36′ 30.8″,

a slightly different value from that given in the American Ephemeris and Nautical Almanac for the year 1894. These are claimed to be the old coördinates.

In the first part of this report is given a table of instrumental errors and Chronometer errors and rates for the entire year. Under the head of extra-meridian is found an account of occultations of stars by the Moon observed with 8-inch and 4½-inch equatorials. From 1864 to end of 1892 494 disappearances and 40 reappearances were recorded. Other observations made were upon the phenomena of Jupiter's satellites, conjunction of Mars with ι Aquarii, comets, double stars and variable stars.

Astronomical and Physical Society of Toronto.—At the meeting of the Astronomical Society of Toronto, Canada, Oct. 31st which was unusually well attended, Dr. Larratt W. Smith, Q. C., presided.

Several members were elected

Letters were read from Miss Agnes M. Clerke, Redcliffe Square, London; Mr. J. Ellard Gore, F. R. A. S., M. R. I. A., Ballysodare, Ireland; and Mr. W. F. Denning, Bristol, England, corresponding members of the society. Each enclosed a special paper. Miss Clerke's is entitled, "The Distance of the Nebulæ;" Mr. Gore's, "The Luminiferous Ether;" Mr. Denning's, "The Radiant Point of the Perseid Meteor Shower." The society appreciates the compliment.

Rev. T. E. Espin, F. R. A. S., of Tow Law, England, announced that a red star (observed at R. A. 20^h 46′ 59″ and N. Decl. 46° 47′) is variable, and is fading.

Four questions respecting magnetism were submitted by Mr. Lindsay.

Mr. A. F. Miller and Mr. Andrew Elvins reported a large sun-spot, visible to the naked eye, which had just passed off the solar disc.

Mr. Arthur Harvey described an aurora observed by himself at Manitowaning on Oct. 7th last.

Messrs. Collins exhibited photographs, including a sharp and clear one of the full Moon.

Dr. J. C. Donaldson of Fergus, Canada, reported a series of lunar observations; also some on close double stars and Jupiter's satellites.

Mr. George E Lumsden stated that at 10 o'clock on the evening of Oct. 10 last a telescope which had shown the Great Red Spot on Jupiter two years ago revealed no trace of it. Seeing was excellent. The place occupied by the Great Red Spot was, at the hour named, on the central meridian of the planet. Mr. Lumsden's inference was that even if the spot is invisible it is still there. On both sides the belts bore the well-known indentations, formed by forcing their way past. He assumed that the spot is variable in color, and that it will again become prominent on Jupiter's disc.

Mr. Harvey presented a small nodule of iron pyrites, given to him as an aerolite. He had been informed that a meteorite weighing several tons which had fallen on Cockburn Island some years ago had been built into a wharf on the island's north side.

Chairman Larratt W. Smith here introduced a pleasant event. The society desired to honor Mr. George E. Lumsden for his indefatigability as corresponding secretary of the society since its incorporation. Mr. John A. Paterson, M. A., read a eulogistic address from the society to Mr. Lumsden, and presented him and his wife on behalf of the members with a beautiful silver urn and a silver inkstand, suitably engraved. A complimentary poem by Librarian G. G. Pursey and a letter from John A. Copeland were also read. Mr. Lumsden accepted the gifts, and replied in a neat speech. Refreshments were served by the lady members.

JOHN A. COPELAND.

New York Academy of Sciences.—*Section of Astronomy and Physics.—Minutes of the Meeting November 13, 1893*—The meeting was called to order at 8:15 P. M. Professor Rees in the chair. The minutes of the previous meeting were read and approved. The secretary read a paper by Mr. Herman S. Davis, Fellow in Astronomy at Columbia College entitled "Note on Bessel's determination of the relative parallaxes of μ and θ Cassiopeiæ." Mr. Davis had re-reduced the observations of Right Ascension difference of the two stars made by Bessel in the years 1814 to 1816, and printed in Engelmann's "Abhandlungen von F. W. Bessel, vol. 2, p. 215." Employing the Auwers' proper motions of the two stars, and introducing into the Besselian equations a term to allow for differential proper motion, Mr. Davis arrives at the value:

$$\begin{array}{ll} \text{Parallax of } \mu \text{ relative to } \theta \text{ Cassiopeiæ} & = +0''.02 \pm 0''.24 \\ \text{where Bessel had obtained} & \;\;\, -0\;.12 \pm 0\;.29 \end{array}$$

It will be seen that the new reduction diminishes materially the probable error of the result, in spite of the fact that the introduction of the proper motion term into the parallax equations has lessened the weight of the determination of the parallax itself. Mr. Davis' result is in very close, though perhaps accidental, accord with that derived from Mr. Rutherfurd's photographic measures, which was $+0''.04$. (Annals N. Y. Academy, Vol. VIII, p. 11).

Professor William Hallock read a paper on "The Theory of Geysers," in which he described his researches upon the geysers of the Yellowstone Park, and explained their action. A glass model geyser was exhibited, in which the internal arrangement and action were plainly shown. Steam was supplied to the model from a small copper boiler, and it reproduced very successfully the remarkably regular periodical eruptions which in Nature are caused by the supply of steam from the interior heated strata of the earth.

After some remarks by various persons the Section adjourned.

HAROLD JACOBY, Secretary of Section.

The Chicago Academy of Sciences—Section of Mathematics and Astronomy—Nov. 7.—Professor S. W. Burnham, Recorder of the Academy of Sciences, reported to the Section that the Board of Supervisors of Santa Clara County, California, had decided to present the astronomical and other photographs made at the Lick Observatory for the exhibit of Santa Clara County at the World's Columbian Exposition, to the Chicago Academy of Sciences for permanent exhibition in their magnificent building now nearly completed in Lincoln Park. These transparencies include some of the beautiful star and comet pictures made by Professor Barnard and a choice section of views about Mt. Hamilton They will be exhibited at the Mid-Winter Exposition at San Francisco, and then returned to Chicago as a gift to the Academy from the County of Santa Clara.

Dr. T. J. J. See of the University of Chicago read a paper on "The Different Methods of Determining the Solar Parallax, and especially on the Method depending upon the Constant of Aberration." The author reviewed the different methods employed by astronomers for finding the distance of the Sun, and gave a résumé of the results obtained in recent investigations of the subject. He pointed out the close agreement of Dr. Gill's parallaxes derived from the observations of Mars and Victoria and Sappho with the parallaxes deduced from the constants of aberration determined by Nyrén, Comstock, Küstner, and Peters, and concluded that the solar parallax will almost certainly lie between 8″.78 and 8″.81, with the chances in favor of 8″.795, which is approximately a mean of the best recent results. Attention was called to Laplace's use of the value 8″.8 in the *Mecanique Celeste* a century ago, and the opinion was expressed that the value 8″.80 might now be safely adopted in the astronomical ephemerides.

Professor Hough pointed out the influence of systematic errors in vitiating results and remarked that the true value of the solar parallax could be obtained only by many separate and independent determinations. Dr. Crew made some remarks on Professor Michelson's determination of the velocity of light, which he considered very exact, and said the existence of aberration showed that the Earth did not carry the ether with it, as some physicists had at one time been led to suppose. Professor Burnham called attention to the tendency of astronomers to over-estimate the accuracy of their results, and said that it was unsafe to trust too implicitly such values even if supported by very small probable errors. It was generally agreed by the speakers that any value of the solar parallax larger than 8″.81 must be regarded as improbable, and that the results deduced from the transit of Venus, even if the observations had been discussed with the utmost rigor, were relatively of no value, as the phenomenon of irradiation known as the "black drop," rendered the *method* worthless. The opposition of Mars and small planets and the constant of aberration were regarded as the only methods at present available for improving our knowledge of the astronomical unit. Adjourned. T. J. J. SEE, Recorder.

BOOK NOTICE

An Astronomical Glossary, or Dictionary of Terms used in Astronomy, with Tables of Data and Lists of Remarkable and Interesting Celestial Objects. By J. E. Gore, F. R. A. S. London, England: Messrs. Crosby, Lockwood & Son, 7 Stationers Hall Court, Ludgate Hill. 1893, pp. 139.

This small book gives explanations of all the terms and names generally used in books on astronomy, and is therefore intended as a reference book both for the beginner and the advanced student. The part called the glossary covers 116 pages, with titles in heavy-faced type, and arranged in alphabetical order. The explanations under these titles are full or complete, according as the title is important. We give two specimens that our readers may judge of the character of them for themselves:

Aberration of Light. An apparent displacement in the position of the stars due to the effect of the Earth's motion in its orbit round the Sun, combined with the progressive motion of light. The result is that "a star is displaced by aberration along a great circle joining its true place to the point on the celestial sphere toward which the Earth is moving." (Barlow & Bryan's Mathematical Astronomy, p. 289.) The amount of aberration is a maximum for stars lying in the direction at right angles to that of the Earth's motion. This is known as the "constant of aberration," and its value in seconds of arc is 206,265 multiplied by the velocity of the Earth, and divided by the velocity of light, or about 20.5″. The motion of the Earth on its axis produces a small aberration called the Diurnal aberration, but the co-efficient of this is very small—only 0.32″—and almost imperceptible in observations. For a star on the celestial equator, viewed from the Earth's equator, the time of transit would be retarded by Diurnal Aberration by only one-fiftieth of a second which could be hardly observed.

Scintillation. A name sometimes applied to the twinkling of the stars.

Besides the part devoted to the glossary there are a number of tables giving useful data pertaining to the Earth, Moon, Sun, Mercury, Venus, Minor Planets, Jupiter, Saturn, Saturn's Rings and Neptune; the Satellites of the outer planets, remarkable red stars, variable stars and binary stars for which orbits have been computed. For so small a book it is a desirable one for reference.

Errata.—Page 732, line 12, for 4th quadrant read 3rd quadrant. Page 888, line 9 from bottom, for prndulum read pendulum; line 7 from bottom for dice read disc.

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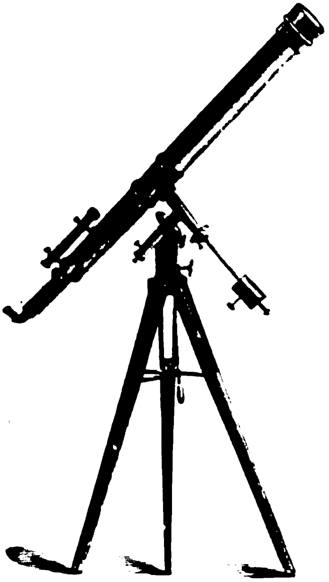

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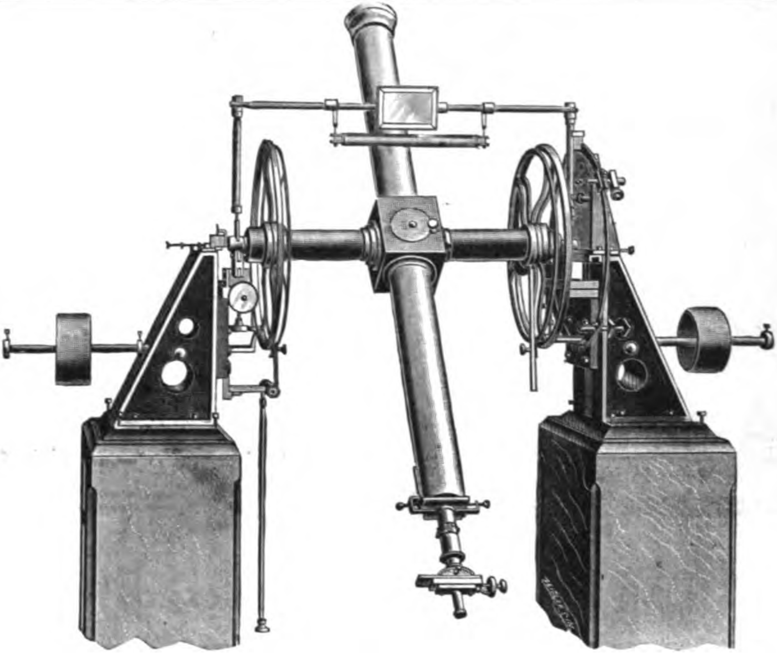

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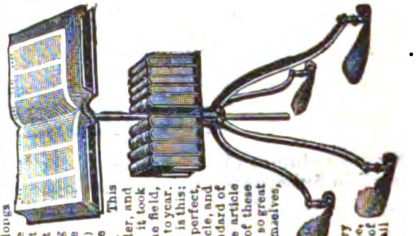

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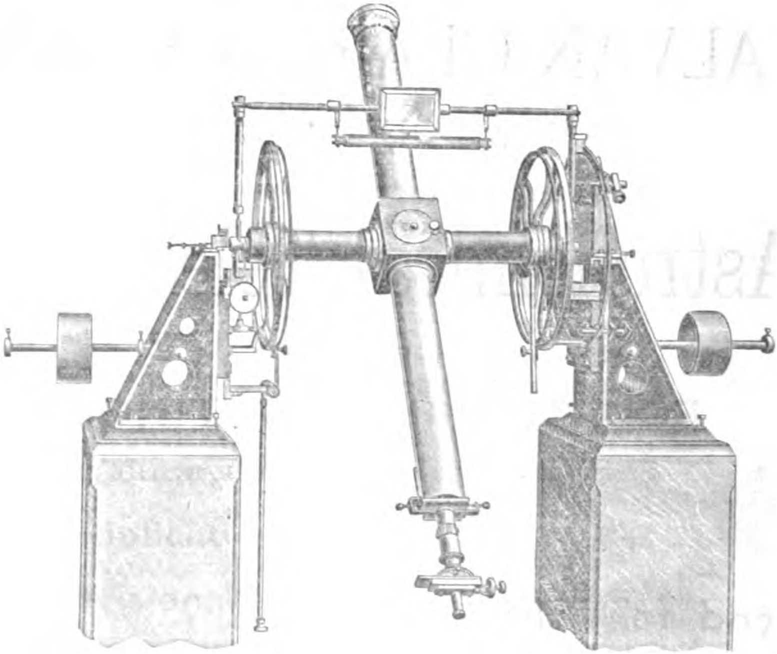


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