a

ASTRONOMY.

CHAMBERS.

I.

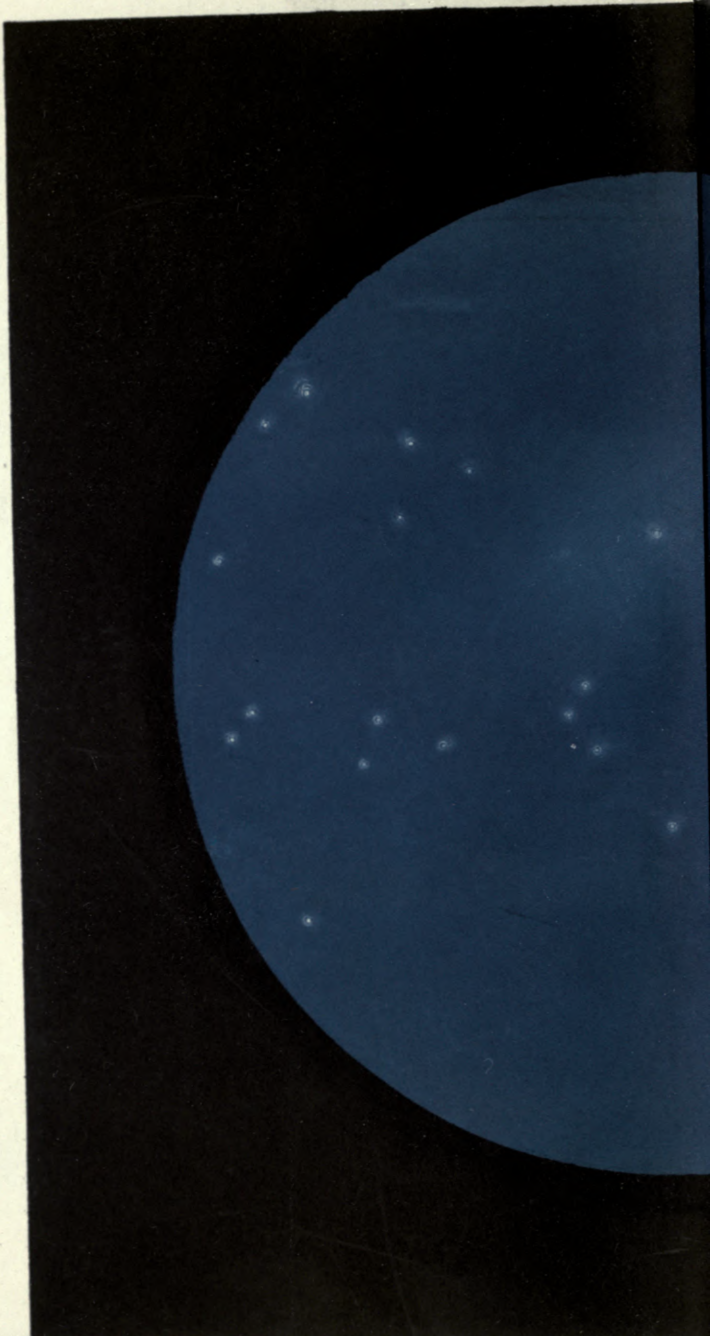
THE SUN, PLANETS, AND COMETS.

London

HENRY FROWDE

OXFORD UNIVERSITY PRESS WAREHOUSE

AMEN CORNER, E.C.



J. Basire sc.

ENCKE'S COMET.

As seen at its re-appearance, on the 22nd of September 1848.

At the Hartwell Observatory.

A HANDBOOK

OF

DESCRIPTIVE AND PRACTICAL ASTRONOMY.

BY

GEORGE F. CHAMBERS, F.R.A.S.,

OF THE INNER TEMPLE, BARRISTER-AT-LAW;

Author of "A Practical and Conversational English, French, and German Dictionary;" "The Tourist's Pocket-Book;" "A Digest of the Law relating to Public Health;" "A Digest of the Law relating to Public Libraries and Museums;" "A Handbook for Public Meetings;" and other Works.

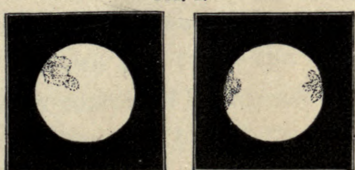
"The heavens declare the glory of God; and the firmament sheweth his handywork."
Psalm xix. 1.

I.

THE SUN, PLANETS, AND COMETS.

FOURTH EDITION.

FIG. 2.



August 26. September 9.

THE IIIRD SATELLITE OF JUPITER IN 1855. (*Secchi.*)

Oxford:

AT THE CLARENDON PRESS.

1889.

PREFACE TO THE FOURTH EDITION.

THE remarks which appear in the Preface to the Third Edition (see *post*) apply almost word for word, so far as they go, to the Fourth Edition. Yet it is necessary for me to write an independent Preface in order to call attention to the altered circumstances under which this work is now presented to the reader. If the development of Astronomy between 1867 and 1877 was great, its development between 1877 and 1889 has been still greater. And besides this, there were important omissions in the ground-plan of the book which I have long been very desirous of making good, whenever time or opportunity became available.

The last edition having reached to nearly 1000 pages it became quite clear that the now necessary additions would have swelled the work to a bulk and consequent price which probably the Public would not have regarded with favour. Accordingly when its division into two volumes became a necessity, I determined to make the two into three, and to complete the undertaking as originally conceived twenty-nine years ago.

The work will therefore henceforth be published in three divisions as follows:—

I. The Sun, Planets, and Comets.

II. Instruments and Practical Astronomy.

III. The Starry Heavens.

It is intended that each volume shall be paged, indexed, and sold separately.

This arrangement, whilst it will be financially more acceptable to the Public, will probably permit in after-years of new editions being brought out at lesser intervals of time than has hitherto been possible.

Subject to the above explanations, it may be further stated that the whole work has been revised everywhere, and enlarged and rearranged wherever alterations seemed necessary or expedient.

A very large number of additional engravings have been prepared, and the list now includes a certain number selected from the various publications of the late Admiral *W. H. Smyth.* My grateful thanks are due to the surviving representatives of the lamented Admiral for their great kindness and liberality in regard to these engravings and other literary materials which they have placed at my disposal. Nor must I omit, in referring to engravings, to mention the kind help which I have received from the Secretaries of the Royal Astronomical Society, the Editor of the *Observatory*, and M. *Gauthier Villars* of Paris.

The Second Volume will it is hoped be published in the Autumn of 1889, and the Third Volume in 1890.

I have been glad to avail myself of the kind assistance of several astronomical friends in passing this volume through the press. To Mr. *A. C. Ranyard*, Mr. *F. C. Penrose*, and Mr. *W. F. Denning* especial thanks are due for particular chapters which are duly noted as they occur; whilst the whole volume has been read for press by the Rev. *J. B. Fletcher*, M.A., of Trinity College, Dublin, and Vicar of All Souls, East-Bourne, and by Mr. *W. T. Lynn*, who has also made himself responsible for all calculations depending on the new value of the Sun's parallax. It may be added that this has been taken at 8·80″, as probably a very close approximation to the truth.

It is now twenty-seven years since the first edition of this work was offered to the public, and from that time (December 1861) to the present it has been, seemingly, a popular and appreciated book both in England and America, maintaining a steady sale from year to year. I am duly grateful for this, the more so as twenty-seven years ago I was a very young Author, with no reason to anticipate such a measure of success, and nothing to back me up in obtaining it.

During this interval of more than a quarter of a century many things have happened in the World of Science, of which Astronomy is only one field. Many new and wholly unlooked-for discoveries have been made: new methods and processes have been introduced. Photography and Spectroscopy in their Astronomical applications may be said to be wholly the creatures of the period above named. New instruments have been invented, and the manufacture of old ones has been enormously developed. In 1860 the 12-inch refractor of the Greenwich Observatory was brought into use and was regarded as a grand advance. Now 12-inches counts for almost nothing in the race between different nations and different makers to obtain telescopes of large size for the exploration of the Heavens.

Looking back on these years, the question forces itself upon our notice: 'Where are we now, in the effort to discover First Causes?' And the answer is: 'Very much where we were a quarter of a century ago.' The Theory of Evolution may be true or it may be false, but, be it one or the other, I agree very much with Professor Mivart, (who believes it,) when he says: "There is no necessary antagonism between the Christian Revelation and Evolution." Evolution is "an attempt to guess at a process; it does not touch the Author of that process, and never will."

G. F. C.

Northfield Grange,
East-Bourne, Sussex:
June, 1889.

PREFACE TO THE THIRD EDITION.

(*EXTRACT.*)

ADVANTAGE has been taken of the call for a new edition of this work to subject the whole, from the first page to the last, to a searching revision. This has proved to be a task of unusual difficulty and labour, in consequence of the astonishing developement which has taken place in the science of Astronomy during the last ten years. And moreover the demands on my time made by professional work have of late been such as to render it very difficult for me to give to Astronomical Studies that close attention which is indispensable if the author of an Astronomical Book would keep his pages up to date and so do justice alike to himself and his readers. It is not open to doubt that this is a matter which sits very lightly upon the consciences of some writers of Text-books. There is scarcely a single page which has not been, to a greater or less extent, dressed up, or in some way amended, with the object of making its statements more accurate in substance or intelligible in diction.

I have to acknowledge a great amount of very useful advice and assistance from observers in all parts of the world, most of them total strangers to me, many of them being persons I had never heard of until the receipt of their letters. Indeed, the letters that I have received, especially from the United States of America, have been a very gratifying encouragement to me to persevere in improving this work in every possible way.

G. F. C.

December, 1876.

PREFACE TO THE SECOND EDITION.

(EXTRACT.)

ASTRONOMY is not cultivated in this country, either as a study or as a recreation, to the extent that it is on the Continent of Europe and in America. And there is a lack of works in the English language which are at one and the same time attractive to the general reader, serviceable to the student, and handy, for purposes of reference, to the professional Astronomer; in fact, of works which are popular without being vapid, and scientific without being unduly technical.

The foregoing observations will serve to indicate why this book has been written. Its aim, curtly expressed, is, general usefulness.

Preferring facts to fancies, I have endeavoured to avoid all those mischievous speculations on matters belonging to the domain of Recondite Wisdom, which have within the last few years borne such pernicious yet natural fruits.

In regard to the matter of bringing up to date, it is believed that the present volume will compare favourably with any of its contemporaries.

G. F. C.

March, 1867.

PREFACE TO THE FIRST EDITION.

(*EXTRACT.*)

ENGLISH literature, abundant though it may be in other respects, is undoubtedly very deficient in works on Astronomy. Our choice is limited either to purely elementary books, few in number, on the one hand; or to advanced treatises, of which there is a similar paucity, on the other. The present work is designed to occupy a middle position between these two classes: to be attractive to the general reader, useful to the amateur, and 'handy' also, as an occasional book of reference, to the professional astronomer.

In pursuance of the plan laid down from the first, theoretical matter is, as a rule, excluded; but in many cases it has been thought desirable not to abide with perfect strictness by this limitation.

Finally, it is hoped that this book may be the means of inducing some, at least, to interest themselves in the study of that noble Science, which in so conclusive a manner shows forth the wonderful Wisdom, Power, and Beneficence of the Great Creator and Omnipotent Ruler of the Universe.

G. F. C.

EAST-BOURNE, SUSSEX:
August, 1861.

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3, note e. *Add* :—A further description of the principle of the method will be found in Challis's *Lectures on Practical Astronomy*, p. 301.

16, Fig. 7. The dotted lines on these 4 discs have been somewhat exaggerated. The curves should neither be quite so sharp, nor the inclination of the straight lines quite so great, as the engraver has made them.

17, line 18. A good description of the details of the structure of a sun-spot is given by Janssen (*Comptes Rendus*, vol. cii. p. 80. 1886).

56, line 3, *for* "Eastern" *read* "Western."

„ line 5, *for* "Western" *read* "Eastern."

„ line 6, *for* "motion" *read* "the apparent motion of revolution round the Sun."

68, line 15, *for* "appendix" *read* "Book VI."

78, line 15. For 0·132′ *read* 0·132.

126. In connection with Sir W. Herschel's supposition that he had seen a volcano in action, on the Moon, attention may be called to some remarks by Prof. Holden in *The Observatory*, vol. xi. p. 334, Sept. 1888.

165, line 8. The minor planet *Thule* (279) is now the most distant one known.

„ line 16, *for* "Massalia" *read* "Massilia."

186, line 8. *Add*:—Lord Stratford De Redcliffe relates that on his voyage to America in September 1820 one night "at anchor on board ship I had occasion to observe the wonderful clearness of the atmosphere. From the *Spartan's* deck I saw with my naked eye the satellites of Jupiter." (*Life of Stratford Canning*, vol. i. p. 299, Lond. 1889.)

189, note f. *Add* :—Some useful information relating to the physical features of Jupiter's satellites will be found in R. Engelmann's *Uber die Helligkeitsverhältnisse der Jupiterstrabanten.* Leipzig, 1871.

200, line 5 of Chapter Contents, *for* "the brothers Ball" *read* "Cassini."

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233. For an account of some curiously mysterious circumstances connected with the discovery of the satellite Titan see a letter by Lynn in *The Observatory*, vol. xi. p. 338, Sept. 1888, and other letters in the numbers of that Magazine for March and April 1889.

250. Newcomb's mass of Uranus is $\frac{1}{22600}$.

259. Newcomb's mass of Neptune is $\frac{1}{19380}$.

320. The Total Eclipse of the Sun of Jan. 1, 1889 was successfully observed in America. Professor Pickering noticed the corona to be longer and more irregular in its shape than usual, and that it exhibited great detail in its filaments.

367. With regard to Wicklow Head, there is another reason why the rise and fall of the tide there is so small. That Head is only about 22 miles N. of Courtown, where the tide waves entering the Irish Sea by the South and by the North of Ireland nearly cancel each other. At Courtown the range of the tide is only 18 inches, and that place is at the head of a *bay*, though a wide and shallow one.

375, line 16, *dele* "periodical."

376, lines 8 and 10, *for* "ecliptic" *read* "zodiac."

377, line 10 from bottom, *read* Aristillus.

" line 3 from bottom, *for* "effect of" *read* "solar."

385, line 14, *after* "these" *insert* "latter."

THE GREEK ALPHABET.

*** The small letters of this alphabet are so frequently employed in Astronomy that a tabular view of them, together with their pronunciation, will be useful to many unacquainted with the Greek language.

α	Alpha.	ν	Nu.
β	Beta.	ξ	Xi.
γ	Gamma.	ο	O-mīcron.
δ	Delta.	π	Pi.
ε	Epsīlon.	ρ	Rho.
ζ	Zēta.	σ	Sigma.
η	Eta.	τ	Tau.
θ	Theta.	υ	Upsīlon.
ι	Iota.	φ	Phi.
κ	Kappa.	χ	Chi.
λ	Lambda.	ψ	Psi.
μ	Mu.	ω	O-mega.

BOOK I.

THE SUN AND PLANETS.

CHAPTER I.

THE SUN. ☉

"O ye Sun and Moon, bless ye the LORD: praise Him, and magnify Him for ever."—*Benedicite.*

Astronomical importance of the Sun.—Solar parallax.—The means of determining it.—By observations of Mars.—By Transits of Venus.—Numerical data.—Light and Heat of the Sun.—Gravity at the Sun's surface.—Spots.—Description of their appearance.—How distributed.—Their duration.—Period of the Sun's Rotation.—Effect of the varying position of the Earth with respect to the Sun.—Their size.—Instances of large Spots visible to the naked eye.—The Great Spot of October 1865.—*Their periodicity.—Discovered by Schwabe.—Table of his results.—Table of Wolf's results.—Curious connexion between the periodicity of sun-spots and that of other physical phenomena.—The Diurnal variation of the Magnetic Needle.—Singular occurrence in September* 1859.—*Wolf's researches.—Spots and Terrestrial Temperatures and Weather.—Ballot's inquiry into Terrestrial Temperatures.—The Physical Nature of Spots.—The Wilson-Herschel Theory.—Luminosity of the Sun.—Historical Notices.—Scheiner.—Faculæ.—Luculi.—Nasmyth's observations on the character of the Sun's Surface.—Huggins's conclusions.—Present state of our knowledge of the Sun's constitution.—Tacchini's conclusions.*

IF there is one celestial object more than another which may be regarded as occupying the foremost place in the mind of the astronomer, it is the Sun: for, speaking generally, there is scarcely any branch of astronomical inquiry with which, directly or indirectly, the Sun is not in some way associated. It will be only appropriate therefore to deal with this important body at the very commencement of a treatise on Descriptive Astronomy[a].

By common consent, the mean distance of the centre of the Earth from the centre of the Sun is taken as the chief unit of astronomical measurement.

The most approved method of determining the value of this was at one time believed to be by the aid of observations of transits of the planet Venus across the Sun[b] (as was first pointed out by Halley). The problem is, for various reasons, an intricate one in practice, but when solved places us in possession of the amount of the Sun's *equatorial horizontal parallax*; in other words, gives us the angular measure of the Earth's equatorial semi-diameter as seen from the Sun's centre, the Earth being at its mean distance from the Sun. With this element given, it is not difficult to determine, by trigonometry, the Sun's distance, expressed in radii of the Earth; reducible thereafter to miles.

Encke, of Berlin, executed an able discussion of the observations of the transits of Venus in 1761 and 1769, and deduced 8·571″ as the amount of the angle in question[c]. From this it was found that the mean distance of the Earth from the Sun is 24065·1 times the equatorial radius of the former (3963 miles), equal to 95,370,000 miles; but these results, excellent as they were once thought to be, have long ceased to command the acceptance of astronomers, the fact being that modern experience has discredited Halley's method.

At a meeting of the Royal Astronomical Society, on May 8, 1857, Sir G. B. Airy proposed to adopt a suggestion of Flamsteed's[d] for determining the absolute dimensions of the solar system, founded upon observations of the displacement of Mars in Right Ascension, when it is far E. of the meridian and far W. of the meridian, as seen from a single observatory; such

[a] Every one who wishes thoroughly to "get up" the Sun should read Young's *Sun*. Secchi's magnificent work *Le Soleil*, of which a second and much enlarged edition was published in 1875, must not be forgotten.

[b] See Book II. *post*.

[c] *Der Venusdurchgang von* 1769, p. 108. Gotha, 1824. Followed by later and better results in the Berlin *Abhandlungen* for 1835, p. 295.

[d] Baily, *Life of Flamsteed*, p. 32.

observations to commence a fortnight before and to terminate a fortnight after the Opposition of the planet. In consequence of the great eccentricity of the orbit of Mars, this method is only applicable to those Oppositions during which the planet is nearly at its least possible distance from the Earth. Airy pointed out the several advantages of this method, viz.:—that Mars may then be compared with stars throughout the night; that it has 2 observable limbs, both admitting of good observation; that it remains long in proximity to the Earth; and that the nearer it is, the more extended are the hours of observation; in all of which matters Mars offers advantages over Venus for observations of displacement in Right Ascension. Airy also entered into some considerations relative to certain of the forthcoming Oppositions, and named those of 1860, 1862, and 1877, as favourable for determining the parallax in the manner he suggested[e].

Le Verrier announced in 1861[f] that he could only reconcile discrepancies in the theories of Venus, the Earth, and Mars, by assuming the value of the solar parallax to be much greater than Encke's value of 8·571″. He fixed 8·95″ as its probable value, though, as Stone pointed out, this conclusion taken by itself rests on a not very solid foundation[g].

The importance of a re-determination was thus rendered more and more obvious, and Ellery, of Williamstown, Victoria, succeeded in obtaining a fine series of meridian observations of Mars, at its Opposition in the autumn of 1862, whilst a corresponding series was made at the Royal Observatory, Greenwich. These were reduced by Stone, and the mean result[h] was a value of 8·932″ for the solar parallax, with a probable error of only 0·032″. This result was singularly in accord with Le Verrier's theoretical deduction. Winnecke's comparison of the Pulkova and Cape observations of Mars yielded 8·964″.

[e] *Month. Not.*, vol. xvii., pp. 208–21. May, 1857. Some practical hints on the conduct of observations are given by A. Hall in *Ast. Nach.*, vol. lxviii., No. 1623, Jan. 16, 1867.

[f] *Annales de l'Observatoire Impérial*, vol. iv., p. 101. Paris, 1861.

[g] *Month. Not.*, vol. xxvii., p. 241. April 1867.

[h] *Month. Not.*, vol. xxiii., p. 185, April 1863.

The Opposition of 1877 was observed under favourable circumstances by Gill at the Island of Ascension, and his observations yielded as their final result a parallax of 8·78″, with a probable error of 0·012″. This implies a mean distance of the Earth from the Sun of 93,080,000 miles[i].

Thus, though there may be some uncertainty in the amount of the correction, there is no doubt that the Sun is nearer than was formerly considered to be the case.

The distance amended to accord with a parallax of 8·8″ is about 92,890,000 miles, with an error not likely much to exceed 150,000 miles[k].

Hansen contributed something towards the elucidation of the matter. As far back as 1854 that distinguished mathematician expressed his belief that the received value of the solar parallax was too small, and in 1863 he communicated to Sir G. B. Airy a new evaluation, derived from his Lunar theory by the agency of the co-efficient of the parallactic inequality. The result was 8·9159″, a quantity fairly in accord with the other values set forth above[l].

Such is a brief statement of the circumstances which caused such special interest to attach to the transits of Venus which were to happen on December 8, 1874, and December 6, 1882: for it was supposed, that, all things considered, transits of Venus were most to be relied on for the purpose of ascertaining the amount of the Sun's parallax. The particular circumstances of the transits in question will come under notice hereafter. Meanwhile it may be stated that Stone has deduced 8·823″ as the general result of all the British observations of the

[i] *Mem.*, R. A. S. xlvi., p. 1, 1881: *Month. Not.*, vol. xli., p. 323. April 1881.

[k] C. A. Young in *Sid. Mess.*, vol. vi., p. 11, Jan. 1887.

[l] *Month. Not.*, vol .xxiv., p. 8. Nov. 1863. The amount of the correction to Encke's determination is about equal to the apparent breadth of a human hair seen from a distance of 125[ft], or that of a sovereign at a distance of 8 miles. The whole amount of the parallax has been put as the measurement of a ball one foot in diameter seen from a station nearly 4·4 miles distant from the ball. Unless the observer can "determine the diameter of the ball so that he shall not be uncertain in his measure to the amount of 0·03 of an inch, his work will not add anything useful to present knowledge." (*Sid. Mess.*, vol. vii., p. 101, March 1888).

1882 transit. The Brazilian result by Wolf and André is 8·808″.

It is almost needless to add that the acceptance of a new value for the solar parallax necessitates the recomputation of all numerical quantities involving the Sun's distance as a unit.

The real mean distance of the Earth from the Sun being ascertained, it is not difficult to determine by trigonometry the true diameter of the latter body, its apparent diameter being known from observation[m]; and, as the most reliable results show that the Sun at mean distance subtends an angle of 32′ 3·6″, it follows that (assuming, as above, a parallax of 8·8″) its actual diameter is 866,200 miles. It is generally accepted that there is no visible compression. The surface of this enormous globe therefore exceeds that of the Earth 11,900 times, whilst the volume is 1,306,000 times greater; since the surfaces of two spheres are to each other as the squares of their diameters, and the volumes as the cubes.

The linear value of 1″ of arc at the mean distance of the Sun is about 450 miles.

The Sun's mass, and consequently its attractive power, is 332,260 times that of the Earth, and (approximately) is 749 times the masses of all the planets put together.

By comparing the volumes of the Sun and the Earth and bringing in the value of their masses, we obtain the relative specific gravity or density of the two.

The Sun's volume is to that of the Earth in the ratio of 1,306,000 to 1; the Sun's mass is to the Earth's in the lesser ratio of 332,260 to 1. Therefore the density of the Sun is to the density of the Earth as 332,260 to 1,331,570, or approximately as 1 to 4. Then taking Baily's value of the density of the Earth (5·67 times that of water), the density of the Sun is 1·42 times that of water.

Some interesting points may conveniently be noted here re-

[m] Lindenau in 1809 and Secchi in 1872 propounded some strange ideas about the visible diameter of the Sun being subject to periodical change, but those ideas met with no favour. (Auwers in *Month. Not.*, vol. xxxiv., p. 22, Nov. 1873.)

specting the consequences which result from the stupendous magnitude and mass of the Sun. At the surface of the Earth a body set free in space falls 16·1^{ft} in the first second of time, with a velocity increasing during each succeeding second. A body similarly set free at the surface of the Sun would start with a velocity 27·4 times as great as that of a body falling at the surface of the Earth. This is equivalent to saying that a pound weight of anything on the Earth would, if removed to the Sun, weigh more than 27^{lb}. Liais has pointed out a singular consequence of this fact:—"An artillery projectile would have on the Sun but very little movement. It would describe a path of great curvature, and would touch the surface of the Sun a few yards from the cannon's mouth." The centrifugal force due to the rotation of any body diminishes gravity at its surface. At the Earth's equator the total diminution is $\frac{1}{289}$ part; whilst at the Sun's equator the centrifugal force is only about $\frac{1}{18000}$ part of the force of gravity. It would be necessary that the Sun should turn on its axis 133 times quicker than it does, for the force of gravity to be neutralised. In the case of the Earth, however, a speed of rotation 17 times as great as it is would suffice to produce the same result. The insignificance of centrifugal force at the Sun's equator, compared with the amount of the force of gravity, suffices to explain the absence of appreciable polar compression in the case of the Sun's disc.

A consideration of the comparative lightness of the matter composing the Sun led Sir J. Herschel to think it "highly probable that an intense heat prevails in its interior, by which its elasticity is reinforced, and rendered capable of resisting [the] almost inconceivable pressure [due to its intrinsic gravitation] without collapsing into smaller dimensions [n]." That the internal pressure exerted by the gases imprisoned within the luminous surface or photosphere of the Sun, must be absolutely stupendous, we have evidence of in the fact of the almost inconceivable velocity (100 to 200 miles per *second*) of the uprushes of incandescent gas and metallic vapours, which are almost constantly taking place

[n] *Outlines of Ast.*, p. 297.

at various parts of its surface. It would seem all but certain that the Sun is nearly wholly gaseous, and that its photosphere consists of incandescent clouds, in which the aqueous vapour of our terrestrial clouds is replaced by the vapours of metals. These considerations, however, introduce a difficulty of a precisely opposite character to that which Sir J. Herschel essayed to combat; inasmuch as, in the light of our present knowledge, it seems hard to conceive how a mere shell of metallic vapour should be able to confine gases at the incomprehensible pressure at which those which rush out in the form of the now well-known "Red Flames" (see *post*) must be confined.

The Sun is to be regarded as a fixed body so far as we are concerned; when therefore we say that the Sun "rises," or the Sun "sets," or the Sun moves through the signs of the zodiac once a year, we are stating only a conventional truth; it is *we* that move and not the Sun, the apparent motion of the latter being an optical illusion.

The Sun is a sphere, and is surrounded by an extensive and rare atmosphere; it is self-luminous, emitting light and heat which are transmitted certainly beyond the planet Neptune, and therefore more than 2700 millions of miles. Of the Sun's heat, it has been calculated that only $\frac{1}{2381000000}$ part reaches us[o], so that what the whole amount of it must be it passes human comprehension to conceive: like many other things in science. Our annual share would be sufficient to melt a layer of ice all over the Earth 100^{ft} in thickness, or to heat an ocean of fresh water 60^{ft} deep from 32° F. to 212° F., according to Herschel and Pouillet[p]. Another calculation determines the direct light of the Sun to be equal to that of 5563 wax candles of moderate size, supposed to be placed at a distance of one foot from the

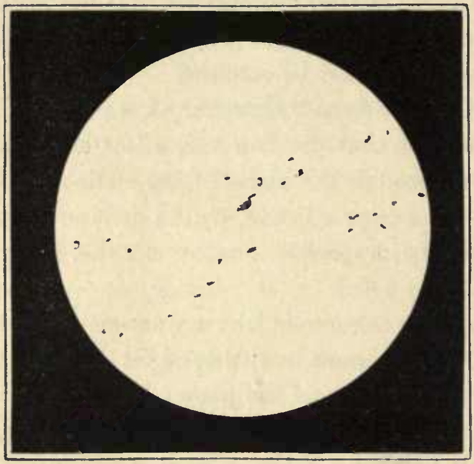
[o] Ganot, *Physics*, p. 391, 7th Eng. ed. 1875. This was calculated on the old value of the solar parallax.

[p] To show the great power of the calorific rays of the Sun, it may be mentioned that in constructing the Plymouth Breakwater, the men, working in diving bells, at a distance of 30^{ft} below the surface, had their clothes burnt by coming under the focus of the convex lenses placed in the bell to let in the light. And houses have been set on fire by the Sun's rays. Langley puts the thickness of the layer of ice which could be melted at 160^{ft}. (*New Ast.*, p. 95.)

observer. The light of the Moon being probably equal to that of only one candle at a distance of 12ft, it follows, according to Wollaston, that the light of the Sun is 801,072 times that of the Moon. Zöllner's ratio is 618,000 to 1, and Bouguer's 300,000 to 1. But all these results rest on a very weak foundation.

If we represent the luminous surface of the Sun when the Earth is at its mean distance, by 1000, the numbers 967 and 1035 will represent the same surface as it appears to us when the Earth is in Aphelion (July) and Perihelion (January) respectively.

Fig. 3.



GENERAL TELESCOPIC APPEARANCE OF THE SUN.

When telescopically examined, there may frequently be seen in the equatorial regions of the Sun dark spots[q] or *maculæ*[r], each usually surrounded by a fringe of a lighter shade, called a *penumbra*[s], the two not passing into each other by gradations of tint, but abruptly. In the few cases in which a gradual shading has

[q] It will appear from what is stated further on that the familiar term "spot" is merely a conventional one used to convey a general idea of what is seen on viewing the Sun. In no precise sense are "spots on the Sun" truly "spots."

[r] Lat. *macula*, a blemish. Dawes upheld a further classification: he applied to the ordinary black central portions the term *umbra* (shadow), on the highly probable ground that the blackness is mainly relative. Patches of deeper blackness are occasionally noticed in the umbræ; Dawes limited to these the designation *nucleus*, sometimes indiscriminately applied to all the blackish area. This classification is adopted in the text. Mr. Langley of the Alleghany Observatory, however, viewing spots with the 13-inch Equatorial of that institution, and a polarising eye-piece (which admits of the employment of the whole aperture), sees that the umbral structure is quite complex, and made up of sunken banks of "filaments" (see *post*). He further perceives that the nucleus which Dawes spoke of as "intensely black," is not black at all, nor even dark (save relatively), but is brilliant with a violet-purple light. (*Month. Not.*, vol. xxxiv. p. 259. March 1874.)

[s] *Pene*, almost; and *umbra*, a shadow.

been noticed, Sir J. Herschel believed that the circumstance may be ascribed to an optical illusion, arising from imperfect definition on the retina of the observer's eye. It is not however always the case that each spot has a penumbra to itself, several spots being occasionally included in one penumbra. And it may further be remarked that cases of an umbra without a penumbra, and the contrary, are on record. Umbræ without penumbræ are exceptional, and may be considered as closely related to physical changes just commencing or terminating. A marked contrast subsists in all cases between the luminosity of the penumbra and that of the general surface of the Sun contiguous. Towards their exterior edges penumbræ are (by contrast) usually darker than nearer the centre. They are frequently very irregular in their outlines (though often they conform somewhat closely to the general contour of the umbræ which they circumscribe), but the umbræ, especially in the larger spots, are frequently of regular form (comparatively speaking, of course); and the nuclei of the umbræ still more noticeably exhibit a compactness of outline.

Spots are for the most part confined to a zone extending 35°, or so, on each side of the solar equator, and are neither permanent in their form nor stationary[t] in their position, frequently appearing and disappearing with great suddenness.

The multitude of facts concerning them, accumulated from the journals of many observers extending over long periods of years, is so great as to bewilder one, and to marshal these in a suitable manner is a task of extreme difficulty: and howsoever performed it is certain that much will have been left out that might with advantage have been inserted.

The general limits in latitude of the spots may be stated, as above, at 35°, but instances of spots seen beyond these limits are on record. In 1871, B. Stewart saw one 43° distant from the solar equator; in 1858, Carrington one 44° 53′; in 1826, Capocci one 46°; in 1846, C. H. F. Peters one 50° 55′; and La Hire, in the

[t] This is not said merely in view of the Sun's rotation; spots sometimes possess an absolute motion of their own.

last century, is said to have seen one in latitude 70°. They are often confined to two belts on either side of the Sun's equator, being frequently absent from the equatorial regions except at particular epochs: from 8° to 20° is their most frequent range, or to be more precise still, their favourite latitude is 17° or 18°. They are often more numerous and of a greater general size in the Northern hemisphere; the zone between 11° and 15° north is particularly noted for large and enduring spots. A gregarious tendency is very obvious, and where the groups are very straggling, the longer line joining extreme ends will pretty generally be found to be more or less parallel to the equator, and not only so, but extending across nearly the whole of the visible disc.

Sir John Herschel remarked:—"These circumstances . . . . point evidently to physical peculiarities in certain parts of the Sun's body more favourable than in others to the production of the spots, on the one hand; and on the other, to a general influence of its rotation on its axis, as a determining cause in their distribution and arrangement, and would appear indicative of a system of movements in the fluids which constitute its luminous surface; bearing no remote analogy to our trade-winds—from whatever cause arising[u]." In reference to the distribution *in latitude* of the spots, the observations of Carrington have placed us in possession of some important facts. That observer found that as the epoch of minimum approached, the spots manifested a very distinct tendency to advance towards the equatorial regions, deserting to a great extent their previous haunts above the parallels of 20° or so. After the minimum epoch had passed, a sudden and marked change set in, the equatorial regions becoming almost deserted by the spots, which on their reappearance showed themselves chiefly in parallels higher than 20°. Wolf finds that the observations of Böhm reveal the fact that the same peculiarity was noticed by that observer in the years 1833–6[v]. Sir John Herschel remarked that if this should prove to be a general rule, "it cannot but

[u] *Outlines of Ast.*, p. 251.

[v] *Month. Not.*, vol. xix., p. 325, July 1859.

1826 : September 29. (*Capocci.*)

1861 : May 21. (*Birt.*)

1861 : May 27. (*Anon.*)

SPOTS ON THE SUN.

stand in immediate and most important connexion with the periodicity itself, as well as with the physical process in which the spots originate."

Confirming Carrington's results in a great measure, Spörer, who has devoted many years to assiduous observation of the Sun, finds that between the time of one minimum and another the region of greatest frequency gradually drifts downward from the zone of 30–25° of latitude to the immediate neighbourhood of the equator; and that at the time of maximum its seat lies in about 17° or 18°. As the next minimum approaches, spots more than 15° from the equator become more rare than spots of 35° and upwards were at the time of maximum. But directly the minimum is past, spots begin to appear again in those higher latitudes where but very few have been seen for several years. This sudden transfer of the seat of energy from a zone where it has been manifested year after year to another and distant zone where nothing has been going on for a long time previously, is a remarkable fact, the import of which cannot at present be explained[w].

The duration of individual spots is a matter associated with extremes both ways. Some remain visible for several months, others scarcely for as many minutes; but a few days or weeks will commonly be found the usual extent of permanency. Some are formed and vanish during the period of a single semi-rotation (rather more than $12\frac{1}{2}^{d}$), others remain during several successive rotations; for it will be readily understood that the Sun, being endued with an axial rotation, and the spots being fixed (or nearly so) on the Sun's surface, it will not be possible for any one spot to remain in sight *continuously* for longer than half the duration of the Sun's rotation.

With respect to the distribution of spots in *longitude* there is little to be said, for it does not certainly appear that they have a preference for any one longitude more than another. Nevertheless Kirkwood believes that this statement so far needs

[w] *Ast. Nach.*, vol. cvii., No. 2565. Dec. 31, 1883. See also *L'Astronomie*, vol. i., p. 70, April 1882.

modification that there is one particular longitude in which planetary influences (see *post*) are specially effective. Spörer also seems to think that there are special localities of disturbance.

When observed for any length of time, a spot will first be noticed on the Eastern limb, disappearing in little less than a fortnight on the Western limb; after an interval of nearly another fortnight, the spot, if still in existence, will reappear on the Eastern side, and in like manner traverse the disc as before. This phenomenon necessarily can only be accounted for on the supposition that the Sun rotates on its axis; and observations specially conducted with that object in view will give the period of this rotation, which Laugier fixed at $25^d\ 8^h\ 10^m$; Carrington at $25^d\ 9^h\ 7^m$; and Spörer at $25^d\ 5^h\ 31^m$—results fairly in accord with Bianchini's determination of $25^d\ 7^h\ 48^m$, deduced in 1718, when the difficulties attending the observations due to the ever-varying forms and actual proper motions of the spots are taken into consideration.

The entire period required by a spot to make a whole visual rotation ($27^d\ 7^h$) is greater than that of the Sun's actual rotation, owing to the Earth's progressive movement in its orbit.

On February 19, 1800, Sir W. Herschel was watching a group, but after looking away for a single moment, he could not find it again[x]. The same observer followed a spot, in 1779, for 6 months; and, in 1840 and 1841, Schwabe observed one and the same group to return 18 times, though not in 18 consecutive rotations of the Sun[y].

In July, August, and September 1859, a large group was followed through several apparitions, and another very noticeable instance of the kind occurred in the autumn of 1865. Similar cases are by no means very rare. It has been surmised, and Sir J. Herschel thought "with considerable apparent probability," that some spots at least are generated again and again, at distant intervals of time, over the same identical

[x] *Phil Trans.*, vol. xci., p. 293. 1801.
[y] *Ast. Nach.*, vol. xviii. No. 418, March 18, 1841.

points of the Sun's body. There appears to be some evidence to bear out this hypothesis[z]. Webb says:—"Fritsch stated that he saw one stand nearly still for 3 days; and Lowe that he even witnessed retrogradation—but these assertions involve a suspicion of mistake. Schröter and others have ascribed to them a more moderate locomotion. This was micrometically established in a lateral direction by Challis in 1857; and Carrington has subsequently made known his very interesting discovery, that there appear to be currents in the photosphere, drifting the equatorial spots forward in comparison with those nearer to the poles, with deviations in latitude of smaller amount: the neutral line as to both these drifts lying in about 15° of latitude. With these shifting landmarks, it is not surprising that the Sun's period of rotation is still doubtful. . . . Howlett and several others have found that spots near the limb require a different focus from those in the centre; arising, no doubt, as Dawes says, from the effect on the retina of very different degrees of brightness[a]." According to Maunder a *relative* displacement amongst the members of the same group amounting to 7000 miles a day is not unusual.

With respect to proper motion, Carrington found that most spots have an independent proper motion of their own (hence uncertainties in conclusions respecting the duration of the Sun's rotation), and not only so, but that the proper motion of spots varies systematically with the latitudes of the spots.

The varying position of the Earth with reference to the Sun, combined with the inclination of the axis of the latter to the plane of the ecliptic (amounting to 82° 45′ according to Carrington; to 83° 3′ according to Spörer[b]), gives rise to the fact that at no two periods of the year do the spots *appear* to traverse the Sun's disc exactly in the same way. About June 5 and December 6 the Earth is in the line of nodes of the spots—or, in

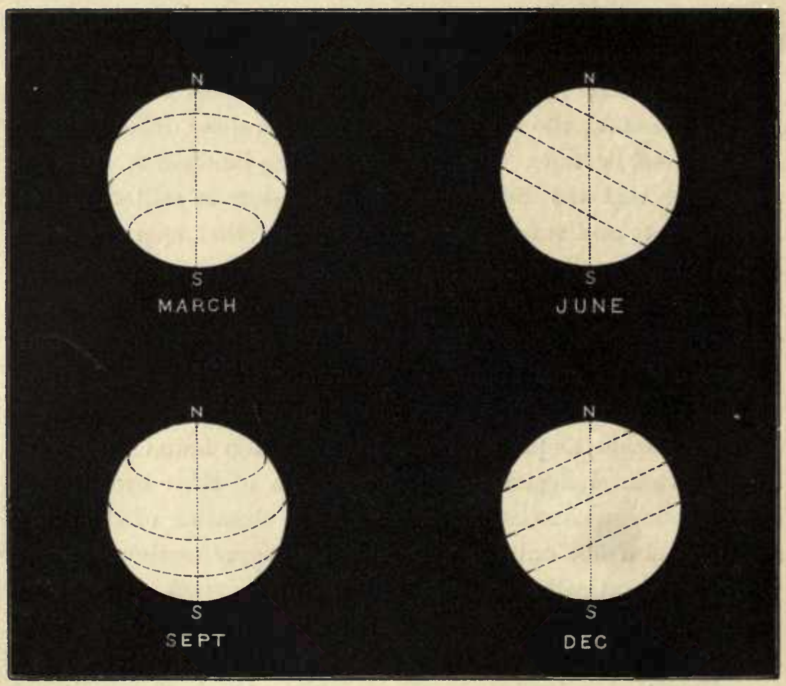
[z] Sir John seems afterwards to have changed his opinion. In a Memoir in the *Quart. Jour. Sc.*, vol. i. p. 225, April 1864, he says exactly the reverse.

[a] *Celest. Objects*, p. 33. (3rd ed.)

[b] The longitude of the ascending node for 1850 was 73° 40′; so that the North pole of the Sun's axis points nearly to π Draconis, and the South one to α Trianguli Australis.

other words, its longitude, as seen from the Sun, corresponds nearly with the points of intersection of the solar equator and the ecliptic—and the paths of the spots are then inclined straight lines. In March the South pole is turned towards us, and the tracks are concave towards the South; in September the conditions are precisely reversed in every respect, the North pole is

Fig. 7.



PATHS OF SUN SPOTS AT DIFFERENT TIMES OF THE YEAR.

turned towards us and the tracks are concave towards the North; at other intermediate periods (not being very near to June 5 or December 6) the paths are both inclined and curved at the same time.

Individual spots also possess many peculiarities of their own. Dawes observed one on January 17, 1852, which, by the 23rd of that month, had rotated in its own plane through 90°. Birt believed that the same thing happened with a spot which he scrutinised in February and March 1859[c]. Schwabe saw occasionally spots of a reddish-brown colour, under circumstances of contrast precluding the possibility of deception; on one occasion 3 telescopes and several bystanders certified to this. In 1826, Capocci perceived a violet haze issuing from each side of the bright central streak of a great double umbra; and during the eclipse of March 15, 1858, Secchi saw a rose-coloured promontory in a spot visible to the naked eye. On April 24, 1886, Hopkins saw a spot with 4 umbræ, 2 of which were black and 2 reddish-brown. The colour was very marked and was visible in different eyepieces, and a bystander confirmed the observation. The colour disappeared in 20 minutes after the observation was commenced[d]. Schwabe described the penumbræ as made up of a multitude of black dots, usually radiating in straight lines from the umbra; Secchi with greater optical power, defined these radiations to be alternate streaks of the bright light of the photosphere and dark veins converging to the umbra[e].

Some Sun-spots are of such prodigious size, as to be visible to the naked eye. A few recent instances are here given. A spot measured by Pastorff on May 24, 1828, was computed to have an area about 4 times the entire surface of the Earth. In June 1843, Schwabe observed one 2′ 47″, or 75,000 miles in diameter. It was seen for an entire week without the aid of a telescope. On March 15, 1858, the day of the celebrated eclipse, a spot having a breadth from W. to E. of 4′, or 108,000 miles, attracted considerable attention. On September 30, in the same year, one having a breadth from W. to E. of 5′ 21″, or 144,450 miles, was observed[f]. On January 26, 1859, and during August 1859, large spots were seen; one visible in the latter month measured nearly 58,000 miles, according to Newall, who saw it distinctly as a notch on the edge of the Sun's disc, the like of

[c] *Month. Not.*, vol. xix., p. 182, March 1859.

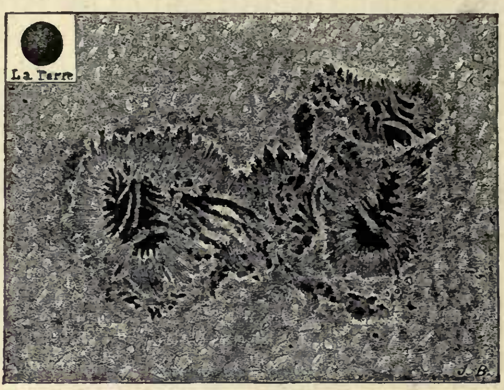
[d] *Month. Not.*, vol. xlvi., p. 393, May 1886.

[e] The preceding facts are given on the authority of Webb, *Celest. Objects*, p. 25. He gives no reference, so I am unable to verify them.

[f] *Ast. Nach.*, vol. l., No. 1182, Feb. 25, 1859.

which he had only seen once before—namely, on March 25, 1850[g]. During April and May 1870, and April 1882, several large spots,

Fig. 8.



GREAT SUN-SPOT VISIBLE ON JUNE 30, 1883. (*Ricco.*)

easy to be seen by the naked eye, were visible. The last-named had on April 19 a length of 2′ 15″ and a breadth of 1′ 15″.

Fig. 9.

THE SAME SUN-SPOT ON JULY 2, 1883. (*Ricco.*)

[g] Letter in the *Times*, Aug. 27, 1859. "An indentation on a globe will disappear in profile unless its breadth and depth are considerable: hence such observations would be rare, but they are recorded by La Hire, 1703; Cassini, 1719; W. Herschel, 1800; Dollond and others, 1846; Lowe, 1849; Newall, 1850, 1859; Observers at Kew and Dessau, 1868."—Webb, *Celest. Objects*, p. 28 (n.). Of late years Indentations have been often recorded in photographs.

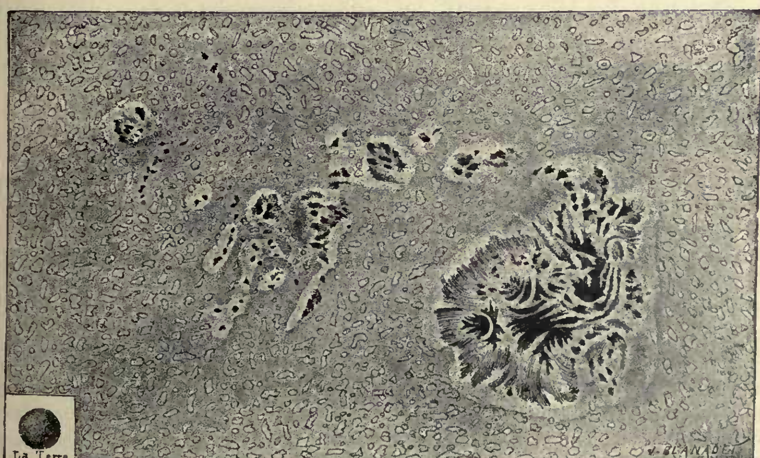
Violent magnetic storms accompanied its appearance. These storms continued from April 14 to April 20[h].

Fig. 10.

GREAT SUN-SPOT VISIBLE ON JULY 25, 1883. (*Ricco.*)

Figs. 8–11 represent 2 large and important spots observed during the summer of 1883 by M. Ricco at Palermo. Their

Fig. 11.



THE SAME SUN-SPOT ON JULY 27, 1883. (*Ricco.*)

[h] Howlett, *Month. Not.*, vol. xlii. p. 356, May 1882.

size relatively to the Earth will be realised generally by comparing them with the shaded ball in the corner of each sketch marked "La Terre."

One of the most interesting large spots ever subjected to careful scrutiny was that which was conspicuously visible in October 1865. Many elaborate observations of it were made by astronomers, and a series of drawings by the Rev. F. Howlett are well known. I here present copies of drawings by Brodie, exhibited at the Royal Astronomical Society[1], which will be useful for comparison with Howlett's. Brodie furnished me with the following revised transcript of his notes :—

"October 11, 1865.—The definition was fine enough to allow this spot to be examined with a power of 470 on an equatorial telescope of 8½ in. aperture and 11½ ft. long. The shape of the spot was tolerably rectangular, the umbra being about 18,000 miles long and 9700 miles wide, or in measures of arc 41·3″ long and 22·3″ wide. The penumbra 86·9″ long and 73·5″ wide. There was an exceedingly long promontory of luminous matter projecting over the umbra from one end of the spot, and running tolerably parallel to the side. Near the end of this promontory was an elongated portion of detached luminous matter of similar shape to that of the promontory itself, about 4000 miles long [see Plate III. Fig. 12]. This portion had elongated itself in a remarkable manner in the previous 15 minutes, for when first observed it was not more than 3000 miles long. The long promontory seemed drifting towards the penumbra, while the detached portion was moving rather away from it, indicating a cyclonic action of the forces in operation.

"About 1½ hours later I found that the detached portion of luminous matter had formed a junction with the long promontory [see Plate III. Fig. 13]. That side of the umbra opposite to this promontory was covered with a sort of 'mackerel sky' formation of misty luminous matter, which extended more or less marked over the whole portion of the umbra. The *black* nucleus of the umbra first noticed by Mr. W. R. Dawes, as generally to be seen in spots, was absent in this umbra. This misty cloud-like appearance of the umbra can only be seen with large telescopes; it seems to be formed by the nodules of luminous matter that break off from the pectinations which fringe the whole of the edge of the umbra; these soon after become more and more diffused, until they become a sort of cloudy stratum floating over the umbra. These nodules invariably drift from the edge of the penumbra towards the centre of the umbra, which would seem to indicate a downward rush of gases from the surface of the sun. On October 12th there were five of these nodules, that had broken off from the ends of the small promontories or pectinations at the edge of the penumbra and had begun to drift on to the umbra, while one had not quite broken away, but was preparing to do so [see Fig. 18]. There was now also another change on the umbra at the end of the long promontory; the misty cloud-like masses of luminous matter began to form into bridge-like formations [see Plate III]

[1] *Month. Not.*, vol. xxvi., p. 21, Nov. 1865.

October 11 ; 11 a.m.

October 11 ; 12.30 p.m.

October 12 ; 9.30 a.m.

October 12 ; 10.30 a.m.

October 12 ; 12.30 p.m.

October 12 ; 2.30 p.m.

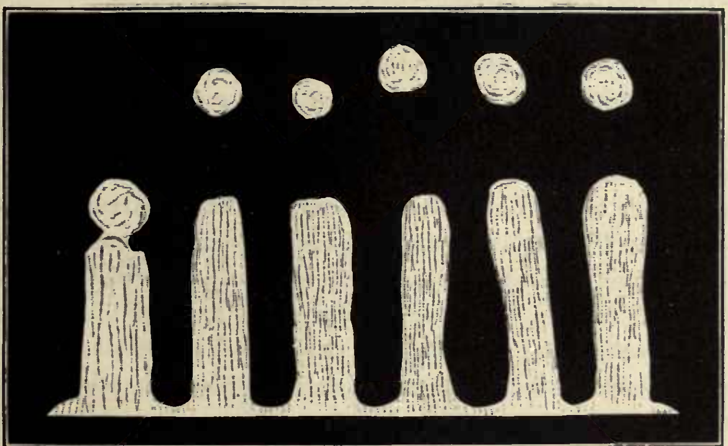
THE GREAT SUN-SPOT OF OCTOBER 1865.

(*Drawn by Brodie.*)

Fig. 13]; but these formations were not nearly so bright and defined as the long portion of the promontory: there was also another shorter promontory formed on the opposite side to that of the long one, or it might be termed an extreme lengthening of one of the pectinations. The rapidity of change in all parts of the umbra was remarkable, the cloudy strata seeming to condense and diffuse very similar to our earth clouds on a summer's day.

"OCTOBER 12.—The shape of the umbra was very greatly altered, and its size was much increased. [See Plate III. Fig. 14]. Its length was nearly 29,000 miles, with a width in the greatest part of 10,400 miles, or 65·2″ of arc long, and 23·6″ wide, the penumbra being 50,000 miles long and 34,000 broad. The long promontory of yesterday had quite disappeared, and there was another formed at the opposite end of the spot of a serpentine form; this was observed at 9.30 A.M. Within an hour another change took place, and at 10.30 this long serpentine promontory had broken

Fig. 18.



THE GREAT SUN-SPOT OF OCTOBER 1865. PECTINATED EDGE VISIBLE ON OCTOBER 12. (*Brodie.*)

into two portions, the shorter end floating on the penumbra. [See Fig. 15]. At 12.30 P.M. the one end of that portion that had broken off had bodily floated towards the penumbra, and formed a junction, as seen in Fig. 16. At 2.30 P.M. the spot was again observed, and the portion originally broken off from the serpentine promontory of the morning had formed a complete bridge across the umbra, [see Fig. 17], while the part from which it was broken had bent round, forming nearly a semicircle. The outline of the spot did not seem to change perceptibly. The figure of the spot was thrown by the telescope on to a board and sketched from its own image.

"OCTOBER 13.—The shape of the spot slightly altered only, but the bridge across had quite disappeared, while the semicircular promontory had formed a junction with the penumbra."

Schwabe said that good eyes would detect without optical aid any spots more than 50″ in diameter, but this is very doubtful.

Probably the minimum limit must be fixed in general at 1′ or even more.

"The origin of a spot, when it can be observed, is usually traceable to some of those minute *pores* or dots which *stipple* the Sun's surface, and which begin to increase, to assume an *umbral* blackness, and acquire a visible and, at first, very irregular and changeable shape. It is not till it has attained some measurable size that a penumbra begins to be formed—a circumstance strongly favouring the origination of the spot in a disturbance from below, upward; *vice versâ*, as the spots decay they become bridged across, the umbræ divide, diminish in size, and close up, leaving the penumbræ, which, by degrees, also contract and disappear. The evanescence of a spot is usually more gradual than its formation. According to Professor Peters and Mr. Carrington, neighbouring groups of spots show a tendency to recede from one another[k]." And not only so, but neighbouring spots in the same group show the same tendency, particularly in longitude. The relative drift of members of the same group is far more noticeable than the relative drift of different groups.

The most casual observer can hardly fail to be struck with the rapidity of the changes which take place in solar spots. Dr. Wollaston says:—"Once I saw, with a 12-inch reflector, a spot burst to pieces while I was looking at it. I could not expect such an event, and therefore cannot be certain of the exact particulars; but the appearance, as it struck me at the time, was like that of a piece of ice when dashed on a frozen pond, which breaks in pieces, and slides on the surface in various directions. I was then a very young astronomer, but I think I may be sure of the fact." Their immense number is likewise very noticeable. On April 26, 1846, Schmidt at Bonn counted upwards of 200 single spots and points in one of the large groups then visible, and 180 in another cluster, in August 1845. On August 23, 1861, I counted 70 distinct spots with a telescope of only 3 inches aperture charged with a power of 21. Schwabe

[k] Sir J. Herschel, in *Quart. Journ. Sc.*, vol. i. p. 225. April 1864.

found that the Western members of a group disappear first, and that at the Eastern end fresh ones are apt to form, where also the junior members are most numerous; that the small points are usually arranged in pairs (much after the appearance of the "Dumb-Bell" Nebula); and that, when near the edge of the Sun, the penumbræ are much brighter on the side next the limb. Sir J. Herschel often noted the penumbræ to be least defined on the preceding side; and Capocci found the principal spot of a group usually the leader. The same observer believed the umbræ to be better defined in their increase than in their decrease. The leader is usually the most black, symmetrical, and enduring of the group, according to Chacornac.

Maunder disagreeing with Schwabe (as above) says that the leader of a group of spots, *i.e.* the most Westerly one, is the darkest and most enduring. He notes that the groups first begin to waste in the central members: then the Eastern members perish; and last of all the Western members.

Attention has now to be directed to one of the most curious and interesting discoveries of modern astronomy—the periodicity of the solar spots. Schwabe, of Dessau, the hero of this[1], shall be introduced to the reader in the words of the late Mr. M. J. Johnson, when, as President of the Royal Astronomical Society, he spoke on the award to him of the Society's Gold Medal in 1857:—

> "What the Council wish most emphatically to express is their admiration of the indomitable zeal and untiring energy which he has displayed in bringing that research to a successful issue. Twelve years, as I have said, he spent to satisfy himself; six more years to satisfy, and still thirteen more to convince, mankind. For thirty years never has the Sun exhibited his disc above the horizon of Dessau without being confronted by Schwabe's imperturbable telescope, and that appears to have happened, on an average, about 300 days a year. So, supposing that he observed but once a day, he has made 9000 observations, in the course of which he discovered 4700 groups. This is, I believe, an instance of devoted persistence (if the word were not equivocal, I should say pertinacity) unsurpassed in the annals of astronomy. The energy of one man has revealed a phenomenon that had eluded even the suspicion of astronomers for 200 years[m]."

[1] Wolf has pointed out that Christian Horrebow first suggested the idea that the spots on the Sun were subject to a periodicity. (R. Wolf, *Geschichte der Astronomie,* p. 654.)

[m] *Month. Not.*, vol. xvii. p. 129. Feb. 1875.

TABLE OF SCHWABE'S RESULTS [n].

Year.	Days of Observation.	Days of no Spots.	New Groups.	Mean diurnal Variation in Declination of the Magnetic Needle.
1826	277	22	118	″ 9·75
1827	273	2	161	11·33
1828	282	0	225	11·38
1829	244	0	199	14·74
1830	217	1	190	12·13
1831	239	3	149	12·22
1832	270	49	84	...
1833	247	139	33	...
1834	273	120	51	...
1835	244	18	173	9·57
1836	200	0	272	12·34
1837	168	0	333	12·27
1838	202	0	282	12·74
1839	205	0	162	11·03
1840	263	3	152	9·91
1841	283	15	102	7·82
1842	307	64	68	7·08
1843	312	149	34	7·15
1844	321	111	52	6·61
1845	332	29	114	8·13
1846	314	1	157	8·81
1847	276	0	257	9·55
1848	278	0	330	11·15
1849	285	0	238	10·64
1850	308	2	186	10·44
1851	308	0	151	8·32
1852	337	2	125	8·09
1853	299	3	91	7·09
1854	334	65	67	6·81
1855	313	146	79	6·41
1856	321	193	34	5·98
1857	324	52	98	6·95
1858	335	0	188	7·41
1859	343	0	205	10·37
1860	332	0	211	10·05
1861	322	0	204	9·17
1862	317	3	160	8·59
1863	330	2	124	8·84
1864	325	4	130	8·02
1865	307	25	93	8·14
1866	349	76	45	7·65
1867	312	195	25	7·09
1868	301	23	101	8·15

Schwabe's observations, as published, end with 1868. The thread is not however absolutely broken, for Wolf had previously

[n] *Month. Not.*, vol. xvi., p. 63. Jan. 1856. Continued to 1868.

started a series of his own. A table of his results, as prepared by himself for this work, at my request, is subjoined :—

Year.	Days of Observation.	Days of no Spots.	Relative Number.	Mean diurnal variation in Magnetic Declination at Prague.	
				Observed.	Calculated.
1849	313	0	95·9	10·27	10·21
1850	325	7	66·5	9·97	8·88
1851	311	0	64·5	8·32	8·79
1852	322	4	54·2	8·09	8·33
1853	332	6	39·0	7·09	7·64
1854	348	67	20·6	6·81	6·82
1855	352	223	6·7	6·41	6·19
1856	356	256	4·3	5·98	6·08
1857	363	70	22·8	6·95	6·92
1858	335	2	54·8	7·41	8·36
1859	334	0	93·8	10·37	10·11
1860	363	0	95·7	10·05	10·20
1861	364	2	77·2	9·17	9·36
1862	359	4	59·1	8·59	8·55
1863	361	2	44·0	8·84	7·87
1864	352	7	46·9	8·02	8·00
1865	361	42	30·5	7·80	7·26
1866	363	85	16·3	6·63	6·62
1867	360	219	7·3	6·47	6·22
1868	351	37	37·3	7·27	7·57
1869	341	2	73·9	9·44	9·22
1870	354	0	139·1	11·47	12·15
1871	363	0	111·2	11·60	10·89
1872	365	0	101·7	10·70	10·47
1873	363	14	66·3	9·05	8·87
1874	363	12	44·6	7·98	7·90
1875	365	132	17·1	6·73	6·66
1876	366	189	11·3	6·47	6·40
1877	365	142	12·3	5·95	6·44
1878	365	281	3·4	5·65	6·04
1879	365	217	6·0	5·99	6·16
1880	366	33	32·3	6·85	7·34
1881	365	5	54·2	7·90	8·33
1882	365	0	59·6	7·92	8·57
1883	365	4	63·7	8·34	8·76
1884	366	0	63·4	8·27	8·74
1885	365	12	52·2	7·83	8·24
1886	365	62	25·4	7·40	7·03
1887	309?	86?	13·5?	6·72	6·48?

The gist of this discovery may be given in a few words :—the spots are subject to a periodical variation in prevalence, extending over about 11^{y}; during this time their numbers follow a cycle which has a maximum and a minimum. At epochs of minima, on many days absolutely no spots are to be seen, as was the case in 1856. It has been hinted that at epochs of maxima, spots are more permanent in character, that is, can be more often watched through several rotations than is the case at epochs of minima: but the idea needs confirmation.

A remarkable discovery has grown out of Schwabe's; namely, that the diurnal variation in the declination of the magnetic needle is characterised by an 11-year period, and (this is the singular circumstance) that the epoch of maximum variation corresponds with the epoch of the maximum prevalence of sun-spots, and *vice versâ*, minimum with minimum. Lamont of Munich announced decisively, about 1850, the fact of the period, and General Sabine, in March 1851 [o], the fact of the coincidence; Gautier and Wolf making the same deduction independently of Sabine and of each other.

Perhaps it might be well just to explain here very briefly what the diurnal variation of the magnetic needle is. The needle is subject daily to a minute change of direction of an oscillatory character. The change is in the nature of an effort on the part of the needle to turn towards the Sun. When the Sun is on the meridian the needle has its mean position; this happens twice in every 24 hours, corresponding to the upper and lower meridian passages of the Sun. Again, when the Sun is mid-way between these positions—also of course twice in every 24 hours—the needle has a mean position because its N. and S. ends make respectively equal efforts (so to speak) to direct themselves towards the Sun. Four times in the day then the needle has its mean position, or, in other words, is directed towards the magnetic meridian. But when the Sun is not in any one of the 4 positions mentioned, that end of the needle which is nearest the Sun is slightly turned away from its mean position and towards the Sun. These diurnal vibrations are not uniform in amount from day to day during a succession of days and months and years: they vary in extent by gradual steps through a period of years, now recognised as being about 11^y. And

[o] *Phil. Trans.*, vol. cxlii. p. 103. 1852.

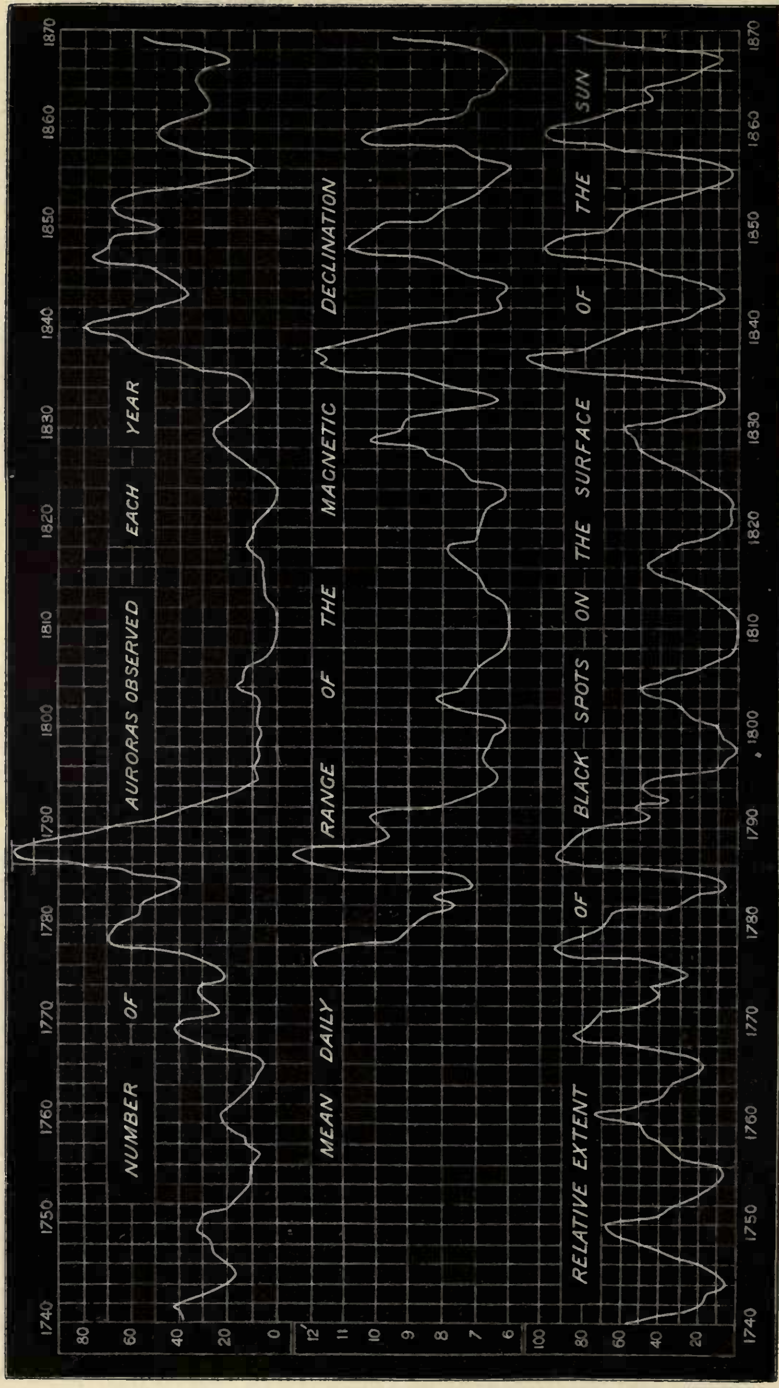


DIAGRAM ILLUSTRATING THE CONNECTION BETWEEN AURORÆ, TERRESTRIAL MAGNETISM, AND SPOTS ON THE SUN.

this fact underlies the coincidence mentioned in the previous paragraph.

Two other curious discoveries have been made in close connection with the foregoing, and it is now accepted that auroræ and magnetic earth currents (currents of electricity which frequently travel below the surface of our globe, and interfere with telegraphic operations) likewise have an 11-year period, and that their maxima and minima are contemporaneous with those of the two phenomena dealt with above; "so that," in the words of Balfour Stewart, "a bond of union exists between these four phenomena. The question next arises, What is the nature of this bond? Now, with respect to that which connects Sun-spots with magnetic disturbances, we can as yet form no conjecture; but we may, perhaps, venture an opinion regarding the nature of that which connects together magnetic disturbances, auroræ, and earth-currents [p]." The reality of the coincidences just adverted to will be best understood by an examination of the accompanying engraving of curves, which I copy from Loomis, who has investigated with great care the historical evidence available for drawing trustworthy conclusions in respect of these matters. Loomis points out that the discrepancies in the coincidences of critical periods in the three phenomena of Sun-spots, magnetic declination, and auroræ are both few and insignificant. His memoir will well repay attentive perusal [q].

Much more might be said on these matters, but a fuller elucidation of them would lead us into non-astronomical fields.

I may here advert to a remarkable phenomenon seen on September 1, 1859, by two English observers whilst engaged in scrutinising the Sun. A very fine group of spots was visible at the time, and suddenly, at $11^h\ 18^m$ a.m., two patches of intensely bright white light were seen to break out in front of the spots. They were at first thought to be due to a fracture of the screen attached to the object-glass of the telescope, but such was

[p] *Proceedings of the Royal Inst.*, vol. iv. p. 58. 1863.

[q] *Silliman's Journal*, vol. v. (3rd s.) p. 245. April 1873; vol. 50. (2nd s.) p. 153. Sept. 1870.

not the case. The patches of light were evidently connected with the Sun itself; they remained visible for about 5^m, during which time they traversed a space of about 33,700 miles. The brilliancy of the light was dazzling in the extreme; but the most noteworthy circumstance was the marked disturbance which (as was afterwards found) took place in the magnetic instruments at the Kew Observatory simultaneously with the appearance in question, followed in about 16^h by a great magnetic storm [r], during which telegraphic communication was impeded, some telegraph offices were set on fire, and auroræ appeared. A storm on the sun not altogether unlike this, it would seem, was observed on September 7, 1871, in America by Professor C. A. Young. A prominence (or uprush of gas) which he was examining with a spectroscope suddenly burst into fragments with great violence. He calculated that the velocity of ascent was as great as 166 miles per second. A portion of the fragments of matter reached 200,000 miles from the Sun's surface [s]. An aurora occurred in the evening [t].

A more recent and extremely striking instance of the correlation of these physical forces occurred on April 16, 1882. A magnificent aurora, violent electrical disturbances, and numerous and large Sun-spots presented themselves simultaneously. The aurora was seen only in America, but the electrical disturbances and of course the Sun-spots were recorded in Europe also. No one can read Mr. H. C. Lewis's paper cited below without being convinced of the intimate association subsisting between these phenomena. Hardly less certain is their magnetic character. Mr. Lewis thus concludes his paper on the aurora in question:—"The theory is not improbable that Sun-spots are the result of solar electrical or magnetic storms, and that auroras are the result of a disturbed electrical condition of the earth, caused by

[r] Carrington and Hodgson, *Month. Not.*, vol. xx. pp. 13–16. Nov. 1859. See also an account of a similar phenomenon noted by Brodie, in vol. xxv. p. 21. November, 1864.

[s] *Nature*, vol. iv. p. 488. Oct. 19, 1871.

[t] For an account of 2 explosions on the Sun seen, the one by Rapin at Lausanne, on Sept. 14, 1883, and the other by C. W. Irish, at Iowa (U. S.), on April 10, 1884, see *L'Astronomie*, vol. iii. p. 381. October 1884.

induction from the Sun. The common cause for both phenomena is probably cosmical[u]."

Wolf has tabulated all the observations of spots which he could collect. These date from 1611, but do not assume good regularity till 1749. Annexed is a copy of Wolf's table[w]. He divides his materials into 2 groups, corresponding to the periods 1610–1738, and 1745–1870, and his deductions as to the average duration of the sun-spot period are as follows:—

SERIES I.	Years.	SERIES II.	Years.
From Mimima,	11·20 ± 2·11.	From Minima,	11·11 ± 1·54.
,, Maxima,	11·20 ± 2·06.	,, Maxima,	10·94 ± 2·52.

Minima.		Maxima.		Minima.		Maxima.	
1610·8		1615·5		1745·0		1750·3	
	8·2		10·5		10·2		11·2
1619·8		1626·0		1755·2		1761·5	
	15·0		13·5		11·3		8·2
1634·8		1639·5		1766·5		1769·7	
	11·0		9·5		9·0		8·7
1645·0		1649·0		1775·5		1778·4	
	10·0		11·0		9·2		9·7
1655·0		1660·0		1784·7		1788·1	
	11·0		15·0		13·6		16·1
1666·0		1675·0		1798·3		1804·2	
	13·5		10·0		12·3		12·2
1679·5		1685·0		1810·6		1816·4	
	10·0		8·0		12·7		13·5
1689·5		1693·0		1823·3		1829·9	
	8·5		12·5		10·6		7·3
1698·0		1705·5		1833·9		1837·2	
	14·0		12·7		9·6		10·9
1712·0		1718·2		1843·5		1848·1	
	11·5		9·3		12·5		12·0
1723·5		1727·5		1856·0		1860·1	
	10·5		11·2		11·2		10·5
1734·0		1738·7		1867·2		1870·6	

[u] *Proceedings Amer. Philos. Soc.*, vol. xx. p. 290, 1882. For further information on the connection between solar outbursts and magnetic storms see the *Stonyhurst College Observations* for 1882, &c. (*Observatory*, vol. vi. p. 307, Oct. 1883.)

[w] *Mem. R. A. S.*, vol. xliii. p. 202, 1877. Wolf's results, as recorded in his paper, will well repay careful study. His system of "relative numbers" to represent the monthly and annual energy displayed by the Sun is extremely interesting, and the preparation of his table to record this energy from July 1749 to June 1876 must have involved incredible labour and research.

The general result may be stated to be, that the period equals 11·111 years (11 years 6 weeks,) but may vary as much as 2 years either way from this average.

Wolf has also considered himself warranted in asserting this law:—"Greater activity in the Sun goes with shorter periods, and less with longer periods"; and further, that there are grounds for the opinion that solar spots and variable stars are due to similar agencies.

Generally speaking, there appears a tendency with maxima to anticipate the middle time between the consecutive minima, the interval $11{\cdot}11^{y}$ being divided into two unequal sub-intervals of $4\frac{1}{2}^{y}$ and $6\frac{1}{2}^{y}$, or, as it may be otherwise put, the maximum appears to fall about the 5th year of the period comprised between 2 minima[x]. Observations of various kinds discussed by De La Rue, Stewart, and Löwy confirm this inequality of interval, but make the sub-intervals $3{\cdot}7^{y}$ and $7{\cdot}4^{y}$, or 1 to 2. As respects the law of increase and decrease in given spot-periods their conclusion differs in an important respect from that of Wolf. He appears to consider that when the spot frequency has descended rapidly or slowly from a maximum value to the next minimum, it ascends with corresponding (relative) rapidity or slowness to the next maximum. De La Rue and his associates prefer to put it that when the spot frequency has passed rapidly or slowly from a minimum to the next maximum, it descends with corresponding (relative) rapidity or slowness to the next minimum[y].

Besides the $11{\cdot}11^{y}$-period Wolf finds another period 5 times as long, and a third period 3 times the length of the second: in other words, that the activity of the Sun goes through a further series of changes every $55\frac{1}{2}^{y}$ and 166^{y}. He fancies that in adjacent or nearly adjacent 11^{y}-periods of unequal length, a greater activity during the shorter tends to compensate, in the total number of spots produced, for a less energy in the longer. The earlier observations are necessarily very imperfect[z].

Schwabe's original period was 10^{y}; but the $11{\cdot}11^{y}$-period is

x Herschel, *Outlines of Ast.*, p. 253.

y *Month. Not.*, vol. xxxii. p. 177. Feb. 1872.

z *Mém. Soc. Phil. de Berne*, 1852. The Table for 1749–1860 is given in *Month. Not.*, vol. xxi. p. 77. Jan. 1861.

now considered preferable; even Schwabe himself assented to it [a], and the investigations of Hansteen and others have shown that it is also the average period of the variation in the magnetic declination.

The examination by Fritsch of a large number of auroral observations enabled him to extend to auroral displays also the 56^y-period, as preferable to the 65^y-period proposed by Olmsted without any reference to the spots.

Another supposed coincidence has now to be adverted to. By carefully examining Schwabe's observations, Wolf thinks that he has detected the existence of minor periods of spot-prevalence, depending in some way upon the Earth, Venus, Jupiter, and Saturn [b]. "Thus he finds a perceptibly greater degree of apparent activity to prevail *annually* on the average of months of September to January than in the other months of the year; and again, by projecting all the results in a continuous curve, he finds in it a series of small undulations succeeding each other at an average interval of 7·65 months, or $0{\cdot}637^y$. Now the periodic time of Venus (225^d) reduced to the fraction of the year is 0·616, a coincidence certainly near enough to warrant some considerable suspicion of a physical connection [c]." It is proper to state that Wolf does not appear to have made any use of Schwabe's observations taken subsequent to 1848 [d].

B. Stewart concurred in the opinion that Planetary influences on the Sun can be traced, and he thinks that Jupiter and Mercury, as well as Venus, are concerned. The general result as to Venus is that spots have a tendency to break out at that portion of the Sun which is nearest to Venus. "As the Sun rotates carrying the newly-born spot farther away from this planet, the spot grows larger, attaining its maximum at the point farthest from Venus, and decreasing again on its approaching this planet."

Doubts must be deemed to attach to the influence assigned to

[a] *Ast. Nach.*, No. 1521, vol. lxix. Ap. 3, 1865.

[b] *Month. Not.*, vol. xix. p. 86. Jan. 1859.

[c] Sir J. Herschel, *Quart. Journ. Sc.*, vol. i. p. 238. April 1864.

[d] *Mittheilungen*, No. 10.

Jupiter and Saturn. As Jupiter's period ($11 \cdot 8^y$) is nearly identical with the Sun-spot period, it has even been suggested that the prevalence of Sun-spots depends *mainly* on influence exerted by Jupiter in different parts of its orbit, in perihelion or aphelion, as the case may be, but the notion seems open to question for several reasons.

Schwabe was disposed to find a connection between Sun-spots and meteoric showers. There is something of a coincidence between three Sun-spot periods and one shower period, but it is no doubt accidental [e].

Sir W. Herschel, considering that the prevalence of numerous spots on the Sun's disc was an indication that probably violent chemical action (with the extrication of an unusual amount of light and heat) was going on, was led to think that years of abundant spots would also be noted for high temperatures and good harvests, and years of few spots for low temperatures and bad harvests [f]. Wolf finds decisive evidence "that years rich in solar spots are in general drier and more fruitful than those of an opposite character, while the latter are wetter and stormier than the former [g]." This idea is supported by meteorological facts collected by an examination of the chronicles of Zürich from 1000 to 1800 A.D. Gautier, from a discussion of 62 sets of observations, extending over 11^y, and taken at various places in Europe and America, arrived at exactly the opposite conclusion [h]. A note of Arago's is highly appropriate here; "In these matters we must be careful not to generalise until we have amassed a large number of observations."

The general question of the influence of the Sun on the meteorology of the Earth is a large and complex one, and it has received very little attention. I propose now to state what is at present known on this subject, though this will scarcely serve any more definite purpose than that of awakening a desire for further knowledge.

Some relationship certainly seems to subsist between solar

[e] *Month. Not.*, vol. xxvii. p. 286. June 1867.

[f] *Phil. Trans.*, vol. xci. p. 316. 1801.

[g] *Mittheilungen*, No. 10.

[h] *Bibl. Univ. de Genève*, vol. li. p. 56. 1844.

spots and terrestrial cloudiness and rainfall. Baxendell considered that diversities of solar activity are to be regarded as causing changes in the magnetic condition of the Earth, and so producing changes in the directions and velocities of the great currents of the atmosphere and in the distribution of barometric pressure, temperature, and rainfall. "The future progress of meteorology must depend to a much greater extent than has been generally supposed, upon the knowledge we may obtain of the nature and extent of the changes which are constantly taking place on the surface of the Sun[i]."

M. Pöey, from an elaborate catalogue of tropical storms, going back as far as 1750, finds evidence of 12 storm cycles indicated by 12 epochs of frequent and severe storms: 10 of these epochs of maximum atmospheric disturbance correspond to maxima of Sun-spots. With respect to epochs of minima the coincidences are less noticeable; for in 11 storm minima only 5 coincidences with Sun-spot minima are to be traced. M. Pöey notes that years marked by storm maxima generally follow by one or two years the years of Sun-spot maxima[k].

A Canadian observer, Mr. A. Elvins, affirms that years in which maxima and minima of Sun-spots occur, are distinguished by general cloudiness, intermediate years being apparently much more free from clouds. He further states that records of the height of the water in Lake Ontario extending over 18 years indicate that a relation subsists between the changes in the Sun's surface and the height of the said water. This latter element is to be viewed of course as indicative of the amount of precipitation that has taken place. Mr. Elvins's general conclusions are that years of maxima and minima of Sun-spots are years of small rainfall and low temperature. He considers, however, that the year immediately preceding a maximum or minimum is usually a specially wet year. If future observations should confirm these ideas, it will (among other things) follow that the rainfall curve

[i] See the statistics on which this is based in *Proc. Lit. and Phil. Soc. of Manchester*, vol. xi. p. 111. They are summarised in *Month. Not.*, vol. xxxiii. p. 249. Feb. 1873.

[k] *Comptes Rendus*, vol. lxxvii. p. 1226. 1873.

is more abrupt than the Sun-spot curve. As regards there being a cycle for storms, Elvins confirms Pöey[l].

Some investigations by an American meteorologist named Brocklesby, of observations extending over 60 years, have led him to consider that in 3 cases out of 5, years of maximum spot energy are years of excess of rainfall; years of minimum spot energy to the number of 5 being, on the other hand, years noticeable in *every* case for deficiency of rainfall. He thinks that his inquiries justify the general deduction that "the rainfall tends to rise above the mean when the Sun-spot area is in excess, and to fall below when there is a deficiency of solar activity[m]."

Professor C. P. Smyth is amongst those who have paid much attention to the subject of Sun-spot cycles and terrestrial temperatures. He considers that a great wave of heat passes over the Earth "every 11 years and a fraction, and *nearly coincidently with the beginning of the increase of each Sun-spot cycle* of the same 11-year duration. The last observed occurrences of such heat-wave (which is very short-lived, and of a totally different shape from the Sun-spot curve), were in 1834·8, 1846·4, 1857·8, 1868·8, whence, allowing for the greater uncertainty in the earlier observation, we may expect," he said, writing in 1872, "the next occurrence of the phenomenon in or about 1880·0." Somewhat less pronounced than the foregoing is *the extreme cold close on either side of the great heat-wave*. Professor Smyth further said in 1872: "We may perhaps be justified in concluding that the minimum temperature of the present cold wave was reached in 1871·1, and that the next similar cold wave will occur in 1878·8." Finally, between the dates of these 2 cold-waves there are 3 "*moderate*" and nearly equi-distant heat-waves, with their 2 intervening and "*very moderate*" cold-waves[n]. Prince, however (a very experienced meteorologist as well as astronomer), says that he does not believe in any weather cycles whatever, though he admits that "a very cold wave was present in 1879," and that "1880 was above the average," and so in a measure confirms Smyth.

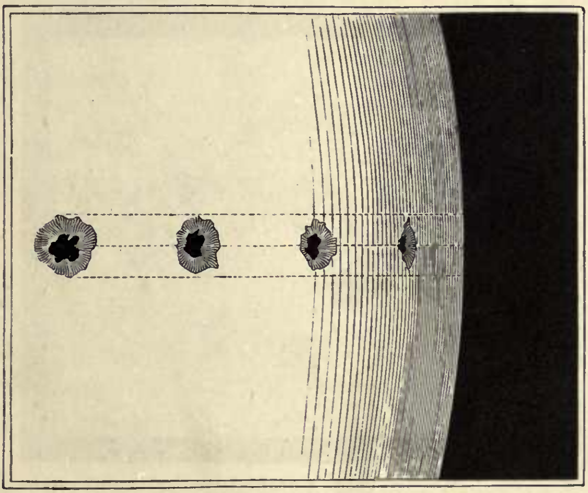
[l] *Ast. Register*, vol. x. pp. 171, 221, and 265. 1872.

[m] *Silliman's Journal*, 3rd Ser., vol. viii. p. 447. Dec. 1874.

[n] *Nature*, vol. v. p. 317. Feb. 22, 1872.

Stone[o], making use of observations at the Cape of Good Hope, extending over 30 years, and Abbe[p], of observations at Munich extending over 60 years, have both traced a connection between the Sun-spot period and terrestrial temperatures. Stone's conclusion, based upon a comparison of curves, is thus expressed by himself:—"I cannot but believe that the same cause which leads to an excess of mean annual temperature leads equally to a dissipation of solar spots." Abbe's conclusion is that there is "a decrease in the amount of heat received from the Sun during the prevalence of the spots." Observations at Oxford (1864–70) show

Fig. 20.



CHANGE OF FORM IN SPOTS OWING TO THE SUN'S ROTATION.

that the mean azimuthal direction of the wind there varied year by year through a range of 58° on the whole, between maximum and minimum of Sun-spots, the tendency of the wind to a *westward* direction increasing with the increase of the spots.

The only other observation which it appears necessary to cite here is by Ballot of Utrecht. He thinks he has established (by means of thermometric observations made at Haarlem, Zwanenbourg, and Dantzig, during a great number of years) the fact that

[o] *Proc. Roy. Soc.*, vol. xix. p. 391. 1871.
[p] *Silliman's Journal*, 2nd Ser., vol. 50. p. 345. Nov. 1870.

†

at each period of $27 \cdot 7^d$ (that of the Sun's *visual* axial rotation) there is in these localities a small elevation of temperature, and a depression at the intermediate epochs.

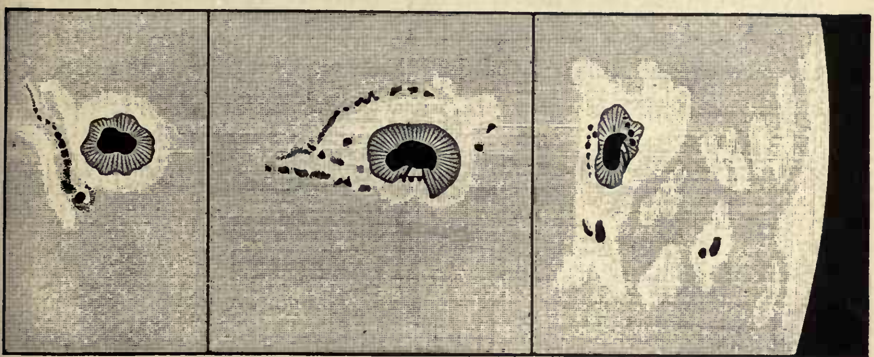
Respecting the physical nature of the spots much uncertainty exists. Up to a comparatively recent period the generally received opinion, however, was that first enunciated by Professor Wilson of Glasgow in 1779, as modified by Sir W. Herschel—namely, that the Sun is surrounded by two atmospheres, of which the outer one is luminous (thence usually termed, after Schröter, the *photosphere*), and the inner one, nearest to the Sun's surface,

Fig. 21.

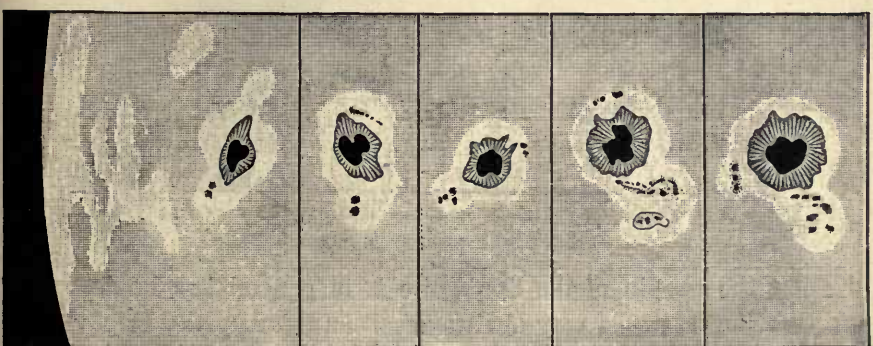
SPOT ON THE SUN MAY 5, 1854, SHOWING CYCLONIC ACTION.

non-luminous, and that the spots are rents or apertures in these atmospheres through which we see the solid body of the Sun, otherwise known to us as the "nucleus" of the spots. This idea is supported by the fact that, when near either limb, the spots are narrower (fore-shortened) than when seen directly in the centre of the disc. The lower stratum is assumed to receive some illumination from the photosphere, and thus to appear *penumbral*; to occupy, in the matter of luminosity, a medium position between the photosphere reflecting much light, and the solid matter reflecting *little*, or, *perhaps*, none at all. The temporary removal of both the strata, but more of the upper than of the lower, he conceived to be effected by powerful upward atmospheric currents, the origin of which is unknown. All, however, that now appears certain is that the nucleus of a spot is lower than the penumbra, and that both are beneath the level

Fig. 22.



July 3. June 30. June 29.

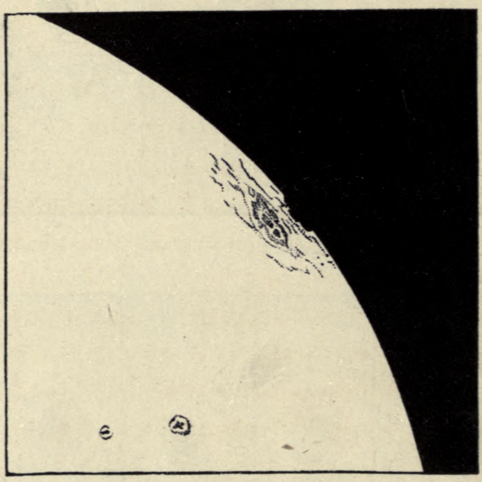


July 8. July 7. July 6. July 5. July 4.

LARGE SPOT ON THE SUN VISIBLE IN 1886, AND SHOWING SUCCESSIVE CHANGES OF FORM OWING TO THE SUN'S ROTATION.

of the Solar photosphere. Detached masses of luminous matter are seen actually to cross a spot without producing any alteration in it. It would seem also that the gases in the space occupied by a spot are at an appreciably lower temperature than those in the brighter parts of the Sun,—and this for the present represents practically the sum of our actual knowledge. That movements of a cyclonic character sometimes occur on the Sun, is sufficiently shown by a well-known drawing made by Secchi on May 5, 1854, of a spot in which a spiral motion is perfectly obvious. Above these atmospheres it is strongly believed that a thin and gaseous envelope exists, more nearly akin to what we understand by the word "atmosphere" as applied to the envelope which surrounds the Earth; and this supposition finds confirmation in the fact

Fig. 23.



A SPOT SEEN ON THE EDGE OF THE SUN EXHIBITING ITSELF AS A DEPRESSION IN THE SUN'S SURFACE.

that the margin of the Sun's disc is in general less luminous than the centre—a very obvious result on this hypothesis.

Fig. 22 is a rough sketch of a large spot on the Sun seen in June and July, 1886, with the naked eye by various observers [p].

Fig. 23 is a representation obtained by photography at Dehra-Dun in India, in 1884, of a spot which, having arrived at the limb of the Sun, exhibited itself as a depression in the Sun's surface.

As regards the luminosity of the Sun's disc at the edge and at

[p] *L'Astronomie*, vol. v. p. 387, Oct. 1886.

the centre, Laplace gives the ratio at 30 to 48; Arago at 40 to 41. The latter figures very greatly underrate the inequality. Secchi, taking the centre at 1, said that the margin is only $\frac{1}{3}$rd or $\frac{1}{4}$th as bright. He said that at times he found himself impeded in his investigations by a ruddiness in the light near the limb. Vogel, the most recent, and, it may be added, the most methodical investigator of this subject, obtained by a photographic expedient the following results; taking the Sun's radius at 12 and the brightness at the centre at 100, the brightness was found to lessen thus:—

Centre	=	100.
4	=	96.
8	=	77.
10	=	51.
Edge	=	13.

Zöllner's investigations indicate that an average black umbra of a Sun-spot is 4000 times as bright as an equal area of surface on a full Moon. This conclusion is supported by the spectroscope, for even a very black umbra yields a spectrum exhibiting all the details of full sunlight [q].

Representing the general brightness of the Sun's disc by 1000, according to Sir W. Herschel that of the penumbræ is 469 and of the nuclei only 7. But it may well be doubted whether all these evaluations are not too fictitiously precise, however generally correct.

The chemical rays given out by different parts of the surface of the Sun also appear to be of unequal power, but whether, like the rays of light, they vary *regularly* from centre to edge, seems a moot point.

As regards the rays of heat, these likewise are radiated more from the centre than from the edges. The Polar regions, too, are colder than the Equatorial, and Secchi has shown that the heat radiated from the spots is less than that from the disc generally. Sir J. Herschel believed one hemisphere to be hotter than the other. That the luminous envelope of the Sun is an incandescent gas, Arago's Polariscope experiment is held to prove [r]. Sir John

[q] Schellen, *Spectrum Analysis*, Eng. ed. p. 293.
[r] See his *Pop. Ast.*, vol. i. p. 419.

Herschel showed that Arago's experiments were by no means conclusive, but spectroscopic observations have brought this matter more within reach of demonstration.

Schwabe's observations seem to indicate that at epochs of minimum spot-display the Sun's surface is more uniformly bright than at other times; that is to say, that there is less absorption or enfeeblement of the Solar light towards the margin of the Sun's disc than is usually the case.

Spots on the Sun seem to have been discovered by J. Fabricius [s] and Galileo, independently, early in 1611, and by Harriot, also independently, in December of the same year. It will readily be understood that the observation of them was one of the first discoveries resulting from the invention of the telescope, though as spots large enough to be visible to the naked eye are now and then visible, they were occasionally seen before that event. Adelmus, a Benedictine monk, makes mention of a black spot on the Sun on March 17, 807 [t]. It is also stated that a similar spot was seen by a Spanish Moor named Averroës, in the year 1161 [u]. An instance of a solar spot is recorded by Hakluyt. He says, that in December 1590, the good ship "Richard of Arundell" was on a voyage to the coast of Guinea, and that her log states that "on the 7 at the going downe of the sunne, we saw a great blacke spot in the sunne, and the 8 day, both at rising and setting, we saw the like, which spot to our seeming was about the bignesse of a shilling, being in 5 degrees of latitude, and still there came a great billow out of the southerboard [x]." The spot was also observed on the 16th.

The natural purity of the Sun seems to have been an article of faith with the ancients, on no account to be called in question; so that we find that when Scheiner (who was a Jesuit at Ingolstadt) reported to his Superior what he had seen, the idea

[s] An interesting account of Fabricius's first observations of a spot on the Sun will be found in Guillemin's *Sun*, p. 127, Eng. Ed.

[t] Bede; Polydorus Vergilius, *Anglicæ Historiæ*.

[u] *Commentary on the Almagest*, quoted by Copernicus, *De Revol. Orb. Cel.*, lib. x.

[x] *The Principal Navigations, Voiages, Traffiques, and Discoueries of the English Nation, &c.*, vol. ii. p. 131. London, 1599.

was treated as a delusion. "I have read," replied the Superior, "Aristotle's writings from end to end many times, and I can assure you that I have nowhere found anything in them similar to what you mention. Go, my son, tranquillise yourself; be assured that what you take for spots in the Sun are the fault of the glasses or of your own eyes." Scheiner in the end, though permitted to publish his opinions[y], was obliged to do so anonymously, so great were the difficulties with which he had to contend as a member of the Church of Rome desiring to cultivate science.

Fig. 24.

FACULÆ ON THE SUN, DEC. 3, 1865. (*Tacchini.*)

In addition to spots, streaks of light may frequently be remarked upon the surface of the Sun towards the equatorial margin of the disc. These are termed *faculæ*[z], and are generally found near spots (just outside the penumbræ) or where spots have previously existed or are soon about to appear; when near the limb of the Sun they are more or less parallel to it. They are of irregular form, and may be likened somewhat to certain kinds of coral, and are more luminous than the solar

[y] In 3 letters addressed to Welser, chief magistrate at Augsburg. Printed copies of these letters were sent to Galileo and others. Schreiner's well-known *Rosa Ursina, &c.* was of later date (1630). Alluding to this enormous book, Delambre says: "There are few books so diffuse and so void of facts. It contains 784 pages; there is not matter in it for 50 pages."—*Hist. Ast. Mod.*, vol. i. p. 690. Either printing must have been cheap or authors rich in those days.

[z] Latin *facula*, a torch.

surface surrounding them. Secchi considered them to be not brighter than the centre of the Sun. They are elevations or ridges in the photosphere, as is proved by Dawes having seen one project above the limb in turning the (apparent) corner into the invisible hemisphere[a], and they have been seen on photographs projecting like a tooth from the limb. Sir W. Herschel saw a facula on December 27, 1799, 2′ 46″ or 74,000 miles long[b]. Faculæ are first alluded to by Galileo in his third letter to Welser[c].

Prominences give gaseous, *i.e.* bright line spectra; faculæ continuous spectra. Faculæ are seen in high latitudes much more frequently than spots are.

Short, the optician, seems to have noticed during the eclipse of July 14, 1748 (O. S.), that the surface of the Sun was covered with irregular specks of light, presenting a mottled appearance not unlike that of the skin of an orange, but relatively much less coarse. The term *luculi*[d] has been applied to the constituent specks. This may perhaps only be an allusion, and the first recorded, to the "granulations" recognised in modern times.

Schwabe found that faculæ and luculi are usually absent at epochs of spot minima[e].

Of late years the Sun has received an unusual amount of attention from astronomers, and many interesting facts have been brought to light concerning its physical appearance[f]. In 1860 Nasmyth with his great reflector (alluded to hereafter) ascertained, it would seem for the first time, that the Sun's surface is covered with a tolerably compact agglomeration of entities, which he likened to *willow leaves*; that is to say, they presented to his eye an appearance similar to that which a rather thin but flattened layer of willow leaves might be expected to exhibit.

As an acrimonious controversy arose in regard to this alleged discovery, it may be fair to lay before the reader Nasmyth's own statement on the subject.

[a] *Month. Not.*, vol. xx. p. 56. Dec. 1859.

[b] *Phil. Trans.*, vol. xci. p. 284. 1801.

[c] *Istoria e Dimostrazioni intorno alle Macchie Solari*, p. 131. Rome, 1613.

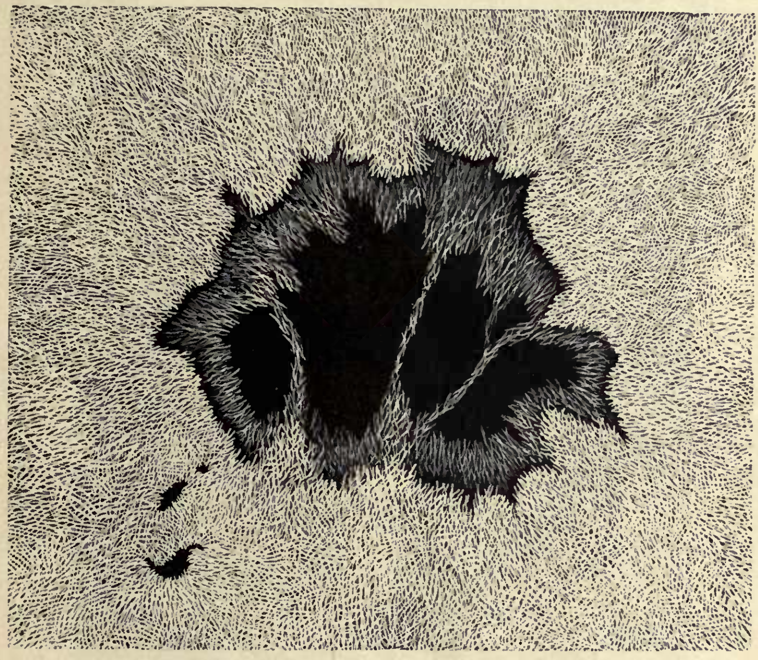
[d] Latin *lucus*, a shining.

[e] *Month. Not.*, vol. xxvii. p. 286. June 1867.

[f] See especially a paper by the Rev. S. J. Perry in *Ast. Reg.*, vol. xxii. p. 257. Nov. 1884.

"In order to obtain a satisfactory view of these remarkable objects, it is not only requisite to employ a telescope of very considerable power and perfection of defining capability, but also to make the observation at a time when the atmosphere is nearly quite tranquil, and free from those vibrations which so frequently interpose most

Fig. 25.



SPOT ON THE SUN, JULY 29, 1860, SHOWING THE "WILLOW-LEAF" STRUCTURE. (*Nasmyth.*)

provoking interruptions to the efforts of the observer; without such conditions as I allude to, it is hopeless to catch even a glimpse of these remarkable and delicate details of the solar surface.

* * * * * * * * * *

"The filaments in question are seen, and appear well defined, at the edges of the luminous surface, where it overhangs 'the penumbra,' as also in the details of the penumbra itself, and most especially are they seen clearly defined in the details of 'the bridges,' as I term those bright streaks which are so frequently seen stretching across from side to side over the dark part of the spot. So far as I have as yet had an opportunity of estimating their actual magnitude, their average length appears to be about 1000 miles, the width about 100.

"There appears no definite or symmetrical arrangement in the manner in which they are scattered over the surface of the Sun; they appear to be across each other in all possible variety of directions. The thickness of the layer does not appear to be very deep, as I can see down through the interstices which are left here and there between them, and through which the dark or penumbral stratum is rendered visible. It is the occurrence of the infinite number of these interstices, and the consequent visibility of a corresponding portion of the dark or penumbral stratum, that gives to the general solar surface that peculiar and well-known mottled appearance which has for a long time been familiar to the observers of the Sun.

"When a solar spot is mending up, as was the case with the one represented, these luminous filaments or willow-leaf-shaped objects (as I term them) are seen to

Fig. 26.

SPOT ON THE SUN, JANUARY 20, 1865. (*Secchi.*)

pass from the edges and extend across the spots, thus forming 'the bridges,' or bright streaks across the spots; if these are carefully observed under favourable conditions, the actual form of these remarkable details, of which 'the bridges' are composed, will be revealed to sight.

"Subsequent observations and considerations of the subject have not caused me to desire to modify or alter the description in the letter above referred to [g]; but only to confirm me in its general correctness. I have no desire to embark in any controversy on the subject, as I prefer to leave to the Sun itself, when carefully observed by adequate means and on favourable occasions, the complete confirmation of what I claim to be the first to discover, delineate, and accurately describe in reference to the structure of his entire luminous surface, as well as the precise form

[g] *Month Not.*, vol. xxiv. p. 66. Jan. 1864.

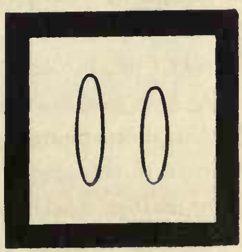
of the structural details, which, from their general similitude in respect to *form*, I at once compared with *willow leaves*[h]."

Nasmyth's views were much canvassed. Several eminent observers of unquestioned good faith, and possessed of first-class instruments and great experience, declared the alleged conformation of the solar surface a myth, whilst others, equally entitled to be heard with respect, avouched their belief in the reality of the discovery. I believe it to be an impartial summing up of the whole case *pro* and *con* to say that there is a very general agreement that innumerable detached (?) masses of unknown nature are scattered over the Sun's surface, and that whether "willow leaves," "rice grains," "granulations," or "shingle beach" be employed to designate them, is rather a matter of taste than evidence of substantial variance. Further, that in the main they do partake of an elliptic outline, and that the average ratio of the axes, whether it be 10 to 1, as Nasmyth first had it, or 4, 3, or 2 to 1, as other observers have since stated it, is, after all, the main point concerning which issue is joined, and even here apparent discrepancies may be ascribable to actual physical change in the bodies themselves.

Writing from Greenwich under date of February 25, 1864, Stone made the following remarks:—

"At the first good opportunity I turned the telescope on the Sun. I may state that my impression was, and it appears to have been the impression of several of the assistants here, that the willow leaves stood out dark against the luminous photosphere. On looking at the Sun I was at once struck with the apparent resolvability of its mottled appearance. The whole disc, as far as I examined, appeared to be covered over with relatively bright rice-like particles, and the mottled appearance seemed to be produced by the interlacing of these particles. I could not observe any particular arrangement of the particles, but they appeared to be more numerous in some parts than in others. I have used the words rice-like particles merely to convey a rough impression of their form; I consider them like the figure.

Fig. 27.



"RICE-LIKE" PARTICLES SEEN ON THE SUN. (*Stone.*)

[h] The preceding paragraphs are taken from a letter reproduced by Nasmyth himself, with a brief supplementary note appended.

"I have seen these rice-like particles on two occasions since, but not so well as on the first day, when the definition was exceedingly good. Yesterday (Feb. 24) I saw them for a few minutes, but with great difficulty. I use the full aperture, 12¾ inches, and a low power. On the first day I saw them [end of January 1864] I called Mr. Dunkin's attention to them. He appears to have seen them, and considers the figure above to represent them fairly. He says, however, that he should not have noticed them if his attention had not been called to them [l]."

A valuable synopsis of the question was presented to the Royal Astronomical Society in 1866 by Huggins [k]. The following is a brief summary of its contents:—

1. *Granule* is the best word to describe the luminous particles on the Sun's surface, as no positive form is thereby implied.

2. The granules are seen all over the Sun, including (occasionally) the surfaces of umbræ and penumbræ. More rarely they can be detected in faculæ.

3. With low powers "rice grains" is a very suitable expression for these granules, but the regularity implied in this designation disappears to a great extent under high magnifiers. There is, however, undoubtedly, a general tendency to an oval contour.

4. The average size of the more compact granules is 1″, of those more elongated 1½″, a few might be 3″, many less than 1″. They appear to be not flat discs, but bodies of considerable thickness.

5. The granules are sometimes packed together rather closely in groups of irregular and straggling outline; at other times they are sparsely scattered. The well-known "mottling" arises wholly from the latter species of combination.

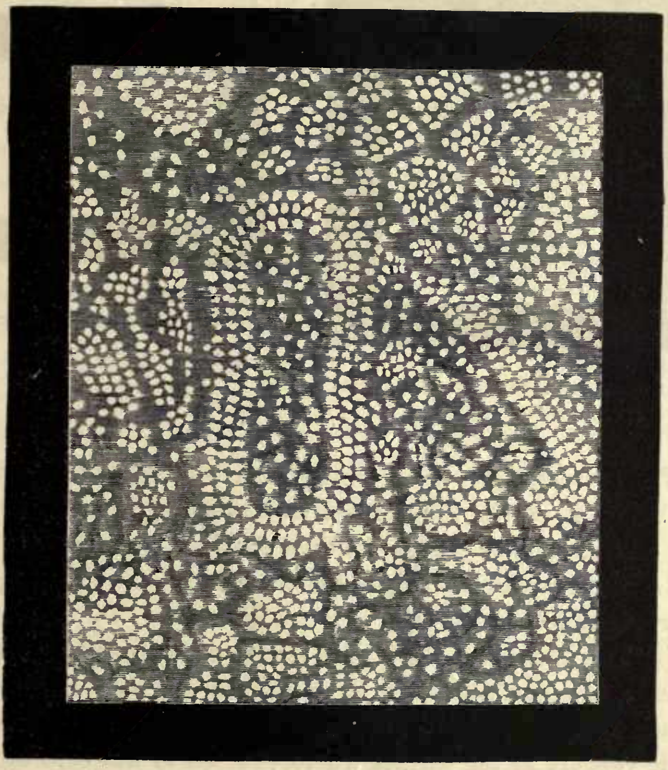
6. The Sun's surface is by no means uniformly level The whole photosphere appears corrugated into irregular ridges and vales, and the granules are possibly masses of rather dense cloud-like matter floating about in the photosphere, considered as composed of more aëriform matter. If the granules really are incandescent clouds, their general oval form may be due to the influence of currents.

[l] *Proceedings of Manchester Lit. and Philos. Soc.*, vol. iii. p. 250, 1864.

[k] *Month. Not.*, vol. xxvi. p. 260. May 1866.

The accompanying figure [28] shows some of the most characteristic modes of grouping of the bright granules noticed by Huggins on different occasions and on various parts of the Sun's surface, brought together, however, in one woodcut for convenience of comparison.

Fig. 28.

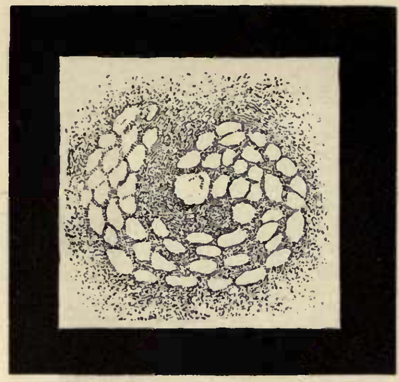


IDEAL VIEW OF THE "GRANULAR" STRUCTURE OF THE SUN. (*Huggins.*)

Huggins has called attention to the fact that Janssen's photographs of 1877 disclose, amongst other important features, a frequent tendency of the granules to arrange themselves in a spiral form, accompanied by more or less loss of distinctness of outline of the individual granules. The same observer has put on record the fact that a similar appearance was noticed by himself as long ago as 1866:—

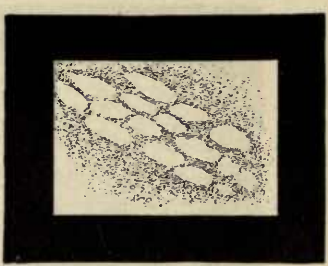
"Saw distinctly the granules. A spiral band of closely associated granules, ending in one of larger size [fig. 26]. In one area near the centre of the Sun's disks the granules appeared more elongated than usual [fig. 30], rather sparsely scattered, and the larger diameters very nearly in the same direction. In neighbouring area, the granules smaller and less elongated. Amongst these no general direction was observed [1]."

Fig. 29.



SOLAR GRANULES 1866, SHOWING CYCLONIC ARRANGEMENT. (*Huggins.*)

Fig. 30.



SOLAR GRANULES 1866, SHOWING ORDINARY ARRANGEMENT. (*Huggins.*)

The present state of our knowledge respecting the physical constitution of the Sun, stated as shortly as possible, is, that the central solid or gaseous body of the Sun is surrounded by a series of concentric envelopes, the order of which reckoning outwards is as follows:—

(1) The *photosphere*, the visible source of the solar light which reaches the Earth, defined by Young as a "shell of luminous clouds formed by the cooling and condensation of the condensible vapours at the surface where exposed to the cold of outer space."

(2) The *chromosphere*, a thin casing of self-luminous gaseous matter, chiefly hydrogen gas in an incandescent state, and the seat of the solar prominences (formerly known as the "red flames" and seen only during total eclipses of the Sun until Lockyer and Janssen independently in 1868 conceived the idea that they might be rendered visible irrespective of the Sun being eclipsed).

[1] *Month. Not.*, vol. xxxviii. p. 102. Jan. 1878.

(3) The *corona*, a vast shell of unknown vapours in a highly attenuated state, many thousands of miles thick, and oberved to extend to at least ½° from what is ordinarily taken to be the visible edge of the Sun.

Tacchini arrived at the following general ideas from observations made by him on 281 days during 1880.

As to the distribution of solar phenomena over the Sun's surface: The spots remain near the equator and present two *maxima* between the parallels 10° and 20° on either side. At the equator they are rare, or wholly absent. Faculæ always occur at the equator; they show *maxima* between $\pm 20°$ and $\pm 30°$, and come nearer the poles than the spots. Protuberances are rare near the equator; they present two principal *maxima* between $\pm 50°$ and $\pm 60°$, and two secondary ones in the latitudes of the faculæ *maxima*. They reach further from the equator than the faculæ, but the polar caps remain free of them. Of the two hemispheres the northern showed, during 1880, the greater activity.

To the cloudy stratum giving rise to the penumbræ Petit assigns a depth exceeding 4000 miles. On the other hand, Phillips considered 300 miles a probable amount. Neither estimate is *primâ facie* entitled to much consideration.

Sir W. Herschel supposed that one of the hemispheres of the Sun is by its physical constitution less adapted to emit light and heat than the other, but the grounds of this conclusion are not known.

The study of the Sun has during the last few years taken a remarkable start, owing to the fact that by the aid of the spectroscope we have been enabled to obtain much new information about its physical constitution. This subject being, however, a physical rather than an astronomical one, and involving a great amount of chemical and optical detail, it cannot conveniently be discussed at length in a purely astronomical treatise, though something will be said concerning it later on in the portion of this work dedicated to spectroscopic matters.

CHAPTER II.

THE PLANETS.

Epitome of the motions of the Planets.—Characteristics common to them all.—Kepler's laws.—Elements of a Planet's orbit.—Curious relation between the distances and the periods of the Planets.—The Ellipse.—Popular illustration of the extent of the Solar system.—Bode's law.—Miscellaneous characteristics of the Planets.—Curious coincidences.—Conjunctions of the Planets.—Conjunctions recorded in History.—Different systems.—The Ptolemaic system.—The Egyptian system.—The Copernican system.—The Tychonic system.

AROUND the Sun, as a centre, certain bodies called Planets[a] revolve at greater or less distances[b]. They may be divided into two groups, (1) the "inferior" planets, or those whose orbits are within that of the Earth, namely Vulcan (?), Mercury, and Venus; and (2) the "superior" planets, or those whose orbits are beyond that of the Earth, namely Mars, the Minor Planets, Jupiter, Saturn, Uranus, and Neptune.

If viewed from the Sun *all* the planets would appear to the spectator to revolve round that luminary in the order of the zodiacal signs; such, however, cannot be the case when the observation is made from one of their number itself in motion, and therefore to us on the Earth the planets *appear* to travel in a capricious manner; and, further, the inferior and superior planets differ the one class from the other in their visible movements.

The Inferior planets are never seen in those parts of the heavens which are in Opposition to the Sun; in other words,

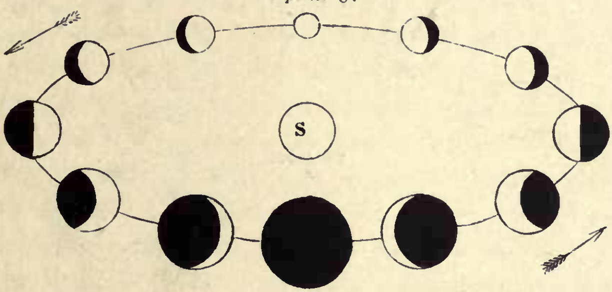
[a] πλανήτης, a wanderer.

[b] The distances of the planets are reckoned in all cases from the centre of the Sun, and not from its surface.

they are never on the meridian at midnight, being always within a short angular distance of the Sun, to the E. or W. of it as the case may be. Twice in every revolution an inferior planet is in *Conjunction* with the Sun [Fig. 31]; in *Inferior Conjunction* when it comes between the Earth and the Sun, and in *Superior Conjunction* when the Sun intervenes between the Earth and the planet. When it attains its greatest distance (as we see it) from the Sun, E. or W., it is said to be at its *Greatest Elongation*, E. or W., as the case may be. In the former case the planet is an "evening star," in the latter a "morning star."

Fig. 31.

Superior ☌.



Inferior ☌.

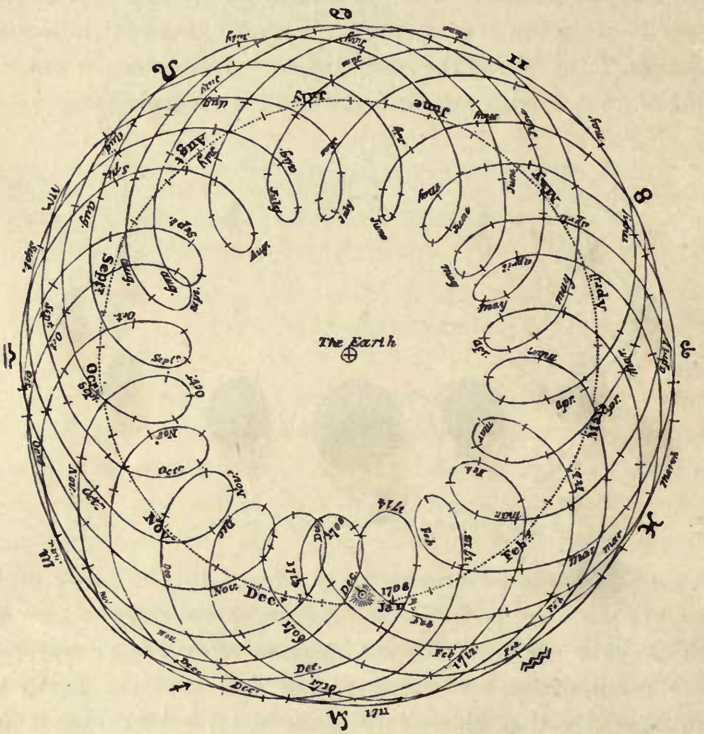
PHASES OF AN "INFERIOR" PLANET.

Although a planet always truly moves in the order of the signs, yet there are periods when it appears *stationary*; sometimes even periods when its motion appears *retrograde* or reversed. These peculiarities are owing to the fact that the Earth has simultaneously a motion of its own in its orbit; and it will readily be understood that they are only apparent and not real. They also obtain with the superior planets. It sometimes (though very rarely) happens that an inferior planet, when in Inferior Conjunction, passes directly between the Earth and the Sun, and is consequently projected on the disc of the latter, which it crosses from E. to W.: this phenomenon is termed a *transit*[c]. Transits will be considered more particularly in Book II (*post*).

[c] *Transire*, to go across.

A superior planet can have any angular distance from the Sun not greater than 180°. After starting from Conjunction with the Sun it successively reaches its Eastern Quadrature (at an angular distance of 90°); and its Opposition at 180°. Proceeding onwards it comes to its Western Quadrature, 270° from

Fig. 32.



APPARENT MOVEMENTS OF MERCURY BETWEEN 1708 AND 1715.

the Sun *reckoned in the direction of its motion*, but only 90° reckoned in the other direction. Another stage of 90° brings it again into Conjunction. A planet cannot have a greater angular distance from the Sun than 180°, because when that is attained it begins to approach the Sun again on the other side, for an obvious geometrical reason.

An exhaustive account of the motions of the planets does not fall within my scope, but the books named in the note may be consulted[d]. How complicated these motions are will be readily understood by an inspection of Fig. 32, which represents the *apparent* movements of Mercury amongst the stars between the years 1708 and 1715.

There are certain characteristics common to all the planets, which are thus enunciated by Hind:—

1. *They move in the same invariable direction round the Sun; their course, as viewed from the north side of the ecliptic, being contrary to the motion of the hands of a watch.*

2. *They describe oval or elliptical paths round the Sun, not however differing greatly from circles.*

3. *Their orbits are more or less inclined to the ecliptic, and intersect it in two points, which are the "nodes;" one half of the orbit lying north, and the other half south of the Earth's path.*

4. *They are opaque bodies like the Earth; and shine by reflecting the light which they receive from the Sun.*

5. *They revolve upon their axes in the same way as the Earth. This we know by telescopic observation to be the case with many planets, and, by analogy, the rule may be extended to all. Hence they will have the alternation of day and night, like the inhabitants of the Earth; but their days are of different lengths to our own.*

6. *Agreeably to the principles of gravitation, their velocity is greatest at those parts of their orbit which lie nearest the Sun, and least at the opposite parts which are most distant from it; in other words, they move quickest in perihelion*[e], *and slowest in aphelion*[f].

From a long series of observations of the planet Mars, Kepler found that certain definite laws might be deduced relative to the motions of the planets, which may be thus stated:—

1. *The planets move in ellipses, having the Sun in one of the foci.*

2. *The radius vector of each planet describes equal areas in equal times.*

[d] Sir J. Herschel's *Outlines of Ast.*, p. 301 *et seq.*; Hind's *Introd. to Ast.*, p. 63 *et seq.* (very good).

[e] περὶ round, and ἥλιος the Sun.

[f] ἀπὸ from, and ἥλιος. The fact here referred to is more strikingly manifest in the case of a comet, owing to the greater eccentricity of cometary orbits: thus the velocity of Donati's comet at perihelion is 127,000 miles per hour, but at aphelion only 480 miles per hour.—(Hind, Letter in the *Times*, Oct. 25, 1858.)

3. *The squares of the periodic times of the planets are proportional to the cubes of their mean distances from the Sun.*

These laws hold good for all the planets and all their satellites. I have already referred in general terms to the 1st law; it may, however, be desirable to say that the orbit of a planet with reference to its form, magnitude, and position, is determined by the 5 following data or *elements*:—

1. *The longitude of perihelion*, or the longitude of the planet, when it reaches this point,—denoted by the symbol π.

2. *The longitude of the ascending node* of the planet's orbit, as seen from the Sun.—☊.

Fig. 33.

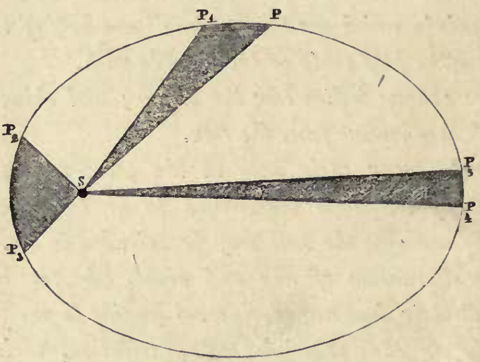


DIAGRAM ILLUSTRATING KEPLER'S SECOND LAW.

3. *The inclination of the orbit*, or the angle made by the plane of the orbit with the ecliptic.—ι.

4. *The eccentricity.*—ϵ. This is sometimes expressed by the angle ϕ, of which ϵ is the natural sine.

5. *The semi-axis-major*, or *mean distance.—a.*

And in order to compute the place of a planet at any given moment, we further need to know:—

6. Its *periodic time* (obtainable from (5) by Kepler's 3rd law); and:—

7. Its *mean longitude*, or place in its orbit, at a given epoch.

Kepler's 2nd law will readily be understood from the annexed diagram. Let P P^2 P^4 be the elliptic path of a planet, and let it move from P to P^1, from P^2 to P^3, and from P^4 to P^5 in equal intervals of time; then the 3 shaded areas, which are assumed to correspond with the movement of the radius vector, will all be equal in area.

The 3rd law involves a curious coincidence, which may be thus expressed:—*If the squares of the periodic times of the planets be divided by the cubes of their mean distances from the Sun, the quotients thus obtained are the same for all the planets.* The following table exemplifies this: it should be remarked, however, that the want of *exact* uniformity in the fourth column[g] is owing to inexactness in the observations on which the calculations are based, as also to the perturbations which the planets mutually exercise on each other's orbits:—

Planet.	a	p	$\frac{p^2}{a^3}$
Vulcan?	0·143	19·7	132716
Mercury	0·38710	87·969	133421
Venus	0·72333	224·701	133413
Earth	1·00000	365·256	133408
Mars	1·52369	686·979	133410
Ceres	2·77692	1679·855	132210
Jupiter	5·20277	4332·585	133294
Saturn	9·53858	10759·220	133375
Uranus	19·18239	30686·821	133422
Neptune	30·03627	60126·722	133413

This law also holds good for the satellites[h], as will be seen from the following tables calculated for the purpose of exemplifying it.

THE SATELLITES OF MARS.

Name.	a	p	$\frac{p^2}{a^3}$
Deimos	2·50	0·319	73611
Phobos	6·00	1·262	73733

[g] The decimal pointing is neglected in all cases in the 4th column, that the eye-appreciation of the coincidences may not be interfered with.

[h] This is not rigorously true when the mass of the primary has an appreciable ratio to that of the Sun.

THE SATELLITES OF SATURN.

Name.	a	p	$\frac{p^2}{a^3}$
Mimas	3·36	0·94	23295
Enceladus	4·31	1·37	23443
Tethys	5·34	1·89	23458
Dione	6·84	2·74	23460
Rhea	9·55	4·52	23457
Titan	22·14	15·95	23442
Hyperion	26·86	21·30	23412
Iapetus	64·54	79·33	23409

THE SATELLITES OF JUPITER.

No.	a	p	$\frac{p^2}{a^3}$
I.	6·05	1·77	14147
II.	9·62	3·55	14156
III.	15·35	7·15	14135
IV.	26·99	16·69	14168

THE SATELLITES OF URANUS.

No.	a	p	$\frac{p^2}{a^3}$
I.	6·94	2·51	18848
II.	9·72	4·14	18664
III.	15·89	8·70	18909
IV.	21·27	13·46	18827

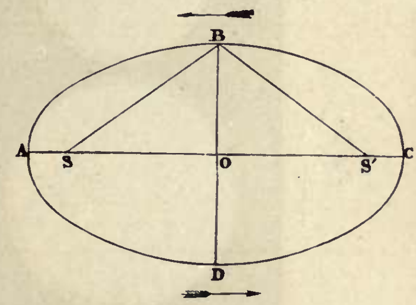
Kepler's laws are the foundation of all planetary astronomy, and it was from them that Newton deduced his theory of gravitation. Arago says: "These interesting laws, tested for every planet, have been found so perfectly exact, that we do not hesitate to infer the distances of the planets from the Sun from the duration of their sidereal revolutions; and it is obvious that this method of estimating distances possesses considerable advantages in point of exactness; for it is always easy to determine precisely the return of each planet to a point in the heavens, while it is very difficult to determine exactly its distance from the Sun."

Sir J. Herschel discussed the theoretical considerations connected with these laws with great perspicuity; and the reader will do well to consult his remarks[1].

A few definitions as to the properties of an ellipse will here be appropriate.

In Fig. 34, S and S′ are the *foci* of the ellipse; A C is the *major axis*; B D the *minor* or *conjugate axis*; O the *centre*: or, astronomically—O A is the *semi-axis-major* or *mean distance*, O B the *semi-axis-minor*; the ratio of O S to O A is the *eccentricity*; the least distance, S A, is the *perihelion distance*; the greatest distance, S C, the *aphelion distance*. S B O is the angle ϕ referred to on p. 58. Where an eccentricity is stated in the form of a vulgar fraction, O S is the numerator and O A the denominator. A decimal expression is to the like effect.

Fig. 34.



THE ELLIPSE.

It will not be difficult to follow in the mind the additional characteristics of a planetary orbit. The orbit in the figure is laid down on a plane surface; incline it slightly as compared to some fixed plane ring and the element of the inclination (as regards its amount) will present itself. (The astronomical fixed plane in this case is that of the ecliptic.) Imagine a planet following the inclined ellipse; at some point it must rise above the level of the fixed plane: the point at which it begins to do so, measured angularly from some settled starting-point, gives the *longitude of the ascending node*. Then the planet's position in

[1] *Outlines of Ast.*, pp. 322–7.

the ellipse when it comes closest to the principal focus, gives us, when projected on the plane ring, the place of nearest approach to

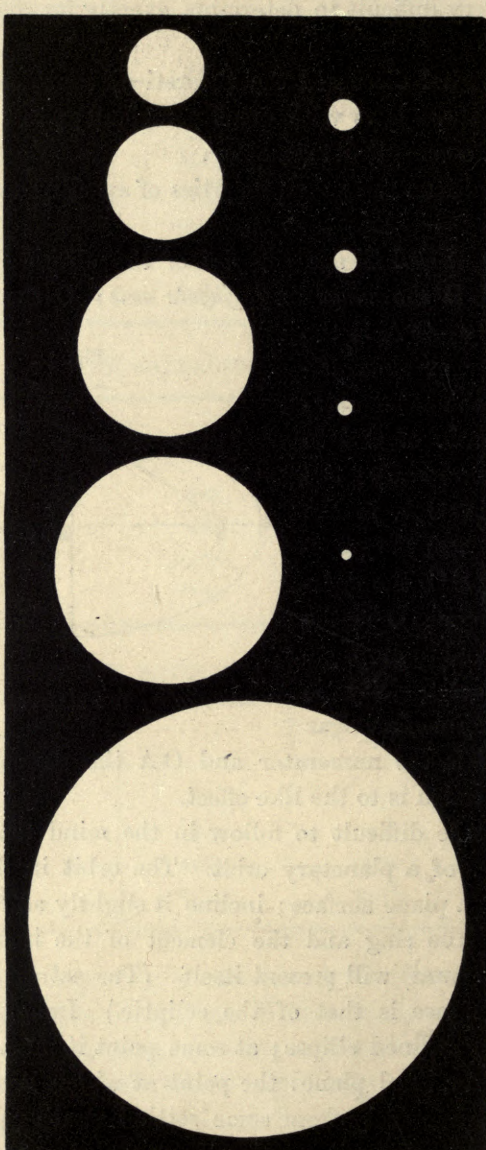
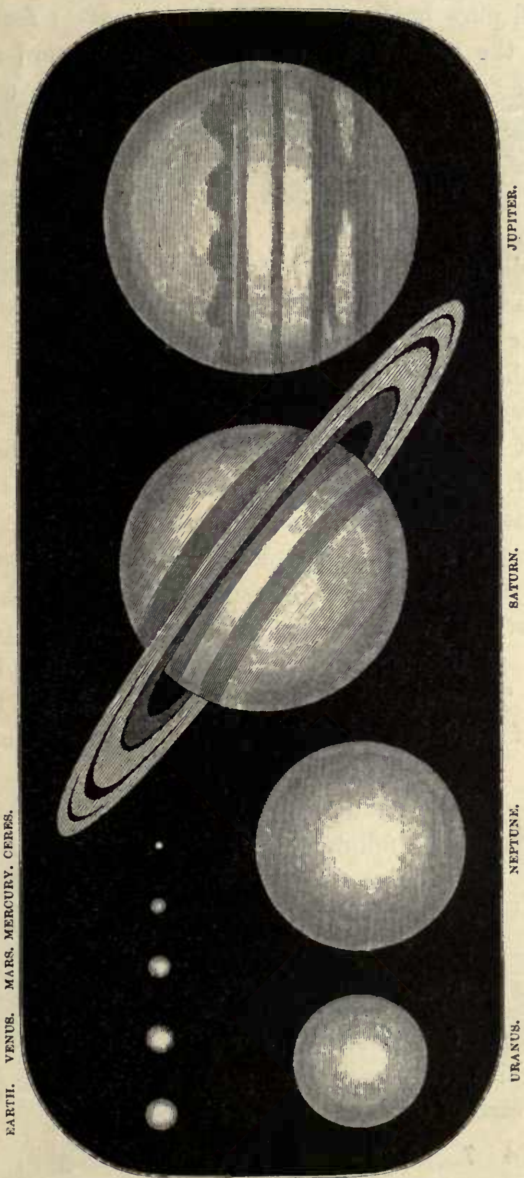


Fig. 35.

RELATIVE APPARENT SIZE OF THE SUN AS VIEWED FROM THE DIFFERENT PLANETS NAMED.

the focus, in other words, the *longitude of the perihelion.* Following these steps, it is not a matter of much difficulty to form a general conception of a planetary orbit in space, for though the method is rather crude, it is so far strictly accurate.

Fig. 36.



COMPARATIVE SIZES OF THE PLANETS.

The following scheme will assist the reader to obtain a fair notion of the magnitude of the planetary system. Choose a level field or open common; on it place a globe 2 feet in diameter, for the Sun; Vulcan (?) will then be represented by a small pin's head, at a distance of about 27 feet from the centre of the ideal Sun; Mercury by a mustard seed, at a distance of 82 feet; Venus by a pea, at a distance of 142 feet; the Earth also by a pea, at a distance of 215 feet; Mars by a small pepper-corn, at a distance of 327 feet; the minor planets by grains of sand, at distances varying from 500 to 600 feet: if space will permit, we may place a moderate-sized orange nearly $\frac{1}{4}$ mile distant from the central point to represent Jupiter; a small orange $\frac{2}{5}$ of a mile for Saturn; a full sized cherry $\frac{3}{4}$ mile distant for Uranus; and lastly a plum $1\frac{1}{4}$ miles off for Neptune, the most distant planet yet known.

Extending this scheme, we should find that the aphelion distance of Encke's Comet would be at 880 feet; the aphelion distance of Donati's Comet of 1858 at 6 miles; and the nearest fixed star at 7500 miles.

According to this scale the daily motion of Vulcan (?) in its orbit would be $4\frac{2}{3}$ feet; of Mercury 3 feet; of Venus 2 feet; of the Earth $1\frac{7}{8}$ feet; of Mars $1\frac{1}{2}$ feet; of Jupiter $10\frac{1}{2}$ inches; of Saturn $7\frac{1}{2}$ inches; of Uranus 5 inches; and of Neptune 4 inches. These figures illustrate also the fact that the orbital velocity of a planet decreases as its distance from the Sun increases.

Connected with the distances of the planets, Bode of Berlin in 1772 published the following singular 'law' of the numerical relations existing between them, which, although not discovered by him but by Titius of Wittemberg in 1766, usually bears his name.

Take the numbers—

0 3 6 12 24 48 96 192 384;

each of which (the second excepted) is double the preceding; adding to each of these numbers 4 we obtain

4 7 10 16 28 52 100 196 388;

which numbers approximately represent the distances of the

Fig. 37. *Plate* V.

SATURN. JUPITER.

MARS. EARTH VENUS. MERCURY.

COMPARATIVE SIZES OF THE SUN AND PRINCIPAL PLANETS.

*** *The disc on the left of the Sun's centre represents* URANUS; *and that on the right,* NEPTUNE.

planets from the Sun expressed in radii of the Earth's orbit, as exhibited in the following table:—

Planets.	True Distance from ☉.	Distance by Bode's Law.
Mercury	3·87	4·00
Venus	7·23	7·00
Earth	10·00	10·00
Mars	15·23	16·00
Ceres	27·66	28·00
Jupiter	52·03	52·00
Saturn	95·39	100·00
Uranus	191·83	196·00
Neptune	300·37	388·00

Bode having examined these relations, and noticing the void between 16 and 52 (Ceres and the other minor planets not being then known), ventured to predict the discovery of new planets; and it may reasonably be believed that this conjecture guided or suggested the investigations of subsequent observers; though some have disputed this[k]. In the above table the greatest deviation between the assumed and the true distance is in the case of Neptune. We may sum up Bode's law as follows:—*That the interval between the orbits of any two planets is about twice as great as the inferior interval, and only half the superior one*[l].

Separating the major planets into two groups, if we take Mercury, Venus, the Earth, and Mars as belonging to the interior; and Jupiter, Saturn, Uranus, and Neptune to the exterior group, we shall find that they differ in the following respects:—

[k] As far back as 450 B.C. Democritus of Abdera thought it probable that eventually new planets would, perhaps, be discovered. (Seneca, *Quæst. Nat.*, lib. vii. cap. 3 and 13.) Kepler was of opinion that some planets existed between the orbits of Mars and Jupiter, but too small to be visible to the naked eye. The same philosopher conjectured that there was another planet between Mercury and Venus.

[l] Many attempts have been made by ingenious dabblers in Astronomy to discover other arithmetical coincidences formed after the spirit of Bode's law. The following is the only one I have met with which deserves reproduction. Take the series 0, 1, 2, 4, 8, 16, 32, and 64: add 4 to each, and the resulting figures represent with some approach to accuracy the relative distances of the satellites of Saturn from their primary.

1. The interior planets, with the exception of the Earth and Mars, are not, as far as we know, attended by satellites, while the exterior planets *all* have satellites. We cannot but consider this as one of the many instances to be met with in the universe of the beneficence of the Creator—in other words, that the satellites of these remote planets are designed to compensate for the small amount of light which their primaries receive from the Sun, owing to their great distance from that luminary.

2. The average density of the first group considerably exceeds that of the second, the approximate ratio being 5 : 1.

3. The mean duration of the axial rotations, or mean length of the day, of the interior planets is much longer than that of the exterior [m]; the average in the former case apparently being about 24^h, but in the latter only 10^h.

In the Appendix will be found a full tabular summary of information concerning the Sun, Moon, and Planets brought up to the latest possible date.

The following coincidences may or may not deserve to be mentioned:—

1. Multiply the Earth's diameter (7912 miles) by 108, and we get 854,496 = ± the Sun's diameter in miles.

2. Multiply the Sun's diameter (852,584 miles) by 108, and we get 92,079,072 = ± the mean distance of the Earth from the Sun.

3. Multiply the Moon's diameter (2160 miles) by 108, and we get 233,280 = ± the mean distance of the Moon from the Earth.

A phenomenon of considerable interest, especially on account of its rarity, is the conjunction, or proximity, of two or more planets within a limited area of the heavens. A noticeable instance is depicted in Fig. 38. It occurred on the morning of July 21, 1859, when Venus and Jupiter came very close to each

[m] This can only be presented as a general conclusion the truth of which seems probable; for it cannot be said with any great confidence what are the rotation periods of any of the planets except the Earth and Mars. It may be presumed, however, that size has more to do with this than distance from the Sun. (See a paper by Denning in the *Observatory*, vol. vii. p. 40, Feb. 1884.)

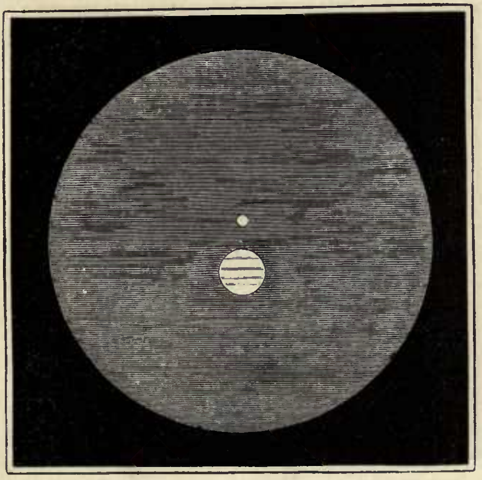
other; at 3^h 44^m A.M. the distance between the two planets was only 13″, and they accordingly appeared to the naked eye as one object.

On Aug. 9, 1886, Venus, Saturn, and δ Geminorum appeared in the same field of the telescope.

During February, 1881, Venus, Jupiter, and Saturn were all in the constellation Pisces, and within a few degrees of one another.

In Sept. 1878, Mercury and Venus were together in the same

Fig. 38.



VENUS AND JUPITER, July 21, 1859.

field of the telescope for some hours. Venus looked like clean silver; Mercury more like lead or zinc, according to Nasmyth.

On Jan. 29, 1857, Jupiter, the Moon, and Venus were in a straight line with one another, though not within telescopic range.

On Dec. 19, 1845, Venus and Saturn appeared in the same field of the telescope. [See Fig. 39.]

On Oct. 3, 1801, Venus, Jupiter, and the Moon were in close proximity in Leo, and Saturn was not far off.

On Dec. 23, 1769, Venus, Jupiter, and Mars were very close to each other.

On March 17, 1725, Venus, Jupiter, Mars, and Mercury appeared together in the same field of the telescope.

On Nov. 11, 1544, Venus, Jupiter, Mercury, and Saturn were enclosed in a space of 10°.

On Nov. 11, 1524, Venus, Jupiter, Mars, and Saturn were very close to each other, and Mercury was only 16° distant.

In the years 1507, 1511, 1552, 1564, 1568, 1620, 1624, 1664, 1669, 1709, and 1765, the three most brilliant planets—Venus, Mars, and Jupiter—were very near each other.

Fig. 39.

VENUS AND SATURN, Dec. 19, 1845.

On Sept. 15, 1186, Mercury, Venus, Mars, Jupiter, and Saturn were in conjunction between the Wheat-ear of Virgo and Libra.

The earliest record we possess of an occurrence of this kind is of Chinese origin. It is stated that a conjunction of Mars, Jupiter, Saturn, and Mercury, in the constellation *Shi*, was assumed as an epoch by the Emperor Chuen-hio, and it has been found by MM. Desvignoles and Kirch that such a conjunction actually did take place on Feb. 18, 2446 B.C., between 10° and 18° of Pisces [n]. Another calculator, De Mailla, fixes upon Feb. 9,

[n] Bailly, *Astron. Ancienne*, p. 345. Desvignoles's original memoir appears in *Mém. de l'Acad. de Berlin*, vol. iii. p. 166, and Kirch's in vol. v. p. 193 of the same series.

2441 B.C., as the date of the conjunction in question; and he states that the four planets named above, and the Moon besides, were comprised within an arc of 12°, extending from 15° to 27° of Pisces. It deserves mention that both the foregoing dates precede the usually received date of the Noachian deluge. It may therefore only be that the planetary conjunction in question was ascertained at some subsequent time.

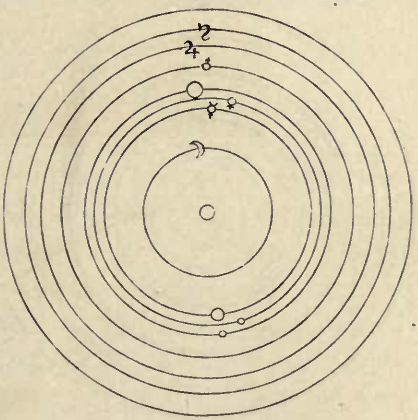
De Mailla gives the following positions °:—

	R.A. °	′	″
Mercury	344	56	16
Jupiter	347	2	12
The Moon	353	18	21
Saturn	354	39	47
Mars	356	45	11

A few general remarks on the different theories of the solar system which have at various times been current will appropriately conclude this chapter.

The *Ptolemaic system* claims the first place in consequence of its wide acceptance and the fame of the astronomer whose name it bears. It would, however, be more correct to say that Ptolemy reduced it into shape rather than that he actually originated it. The Earth was regarded as the centre, and around this the Moon (☽), Mercury (☿), Venus (♀), The Sun (☉), Mars (♂), Jupiter (♃), and Saturn (♄), all called *planets*, were assumed to revolve in the order in which I have here given them.

Fig. 40.



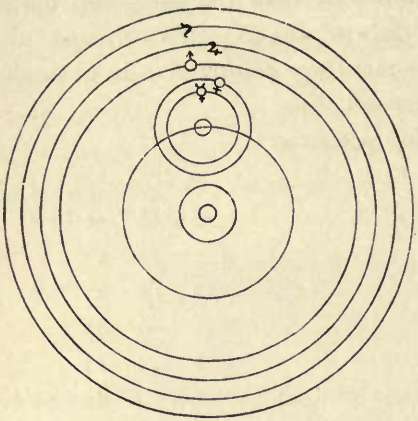
THE PTOLEMAIC SYSTEM.

More accurate ideas were, however, current even before

° *Hist. Gén. de la Chine*, vol. i. p. 155.

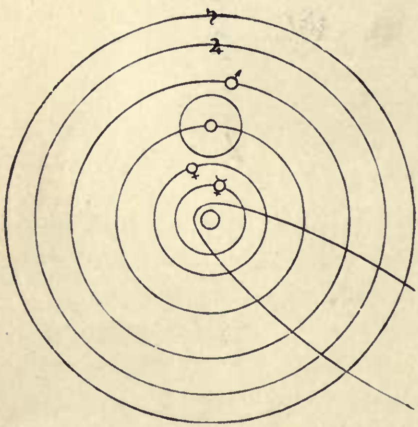
Ptolemy's time, but they found few supporters. Aristarchus of Samos, who lived about 280 B.C., supposed, according to Archimedes and Plutarch, that the Earth revolved round the Sun, for which 'heresy' he was accused of impiety. Cleanthes of Assos, who flourished but 20 years later, was, according to Plutarch, the first who sought to explain the great phenomena of the universe by supposing a motion of translation on the part of the Earth around the Sun, together with one of rotation on its own axis. The historian relates that this idea was so novel and so contrary to the received notions that it was proposed to arraign Cleanthes also for impiety.

Fig. 41.



THE EGYPTIAN SYSTEM.

Fig. 42.

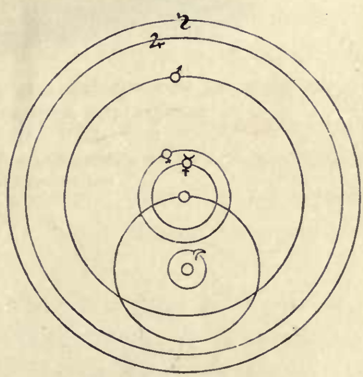


THE COPERNICAN SYSTEM.

The *Egyptian system* differed from the Ptolemaic only in regarding Mercury and Venus as satellites of the Sun and not primary planets.

A long period elapsed before any new theories of importance were started, but in the 16th century of the Christian era *Copernicus* came forward and propounded his theory, which ultimately superseded all others, and is the one now (in substance) adopted. It places the Sun in the centre of the system as the point around which all the primary planets revolve. It must not be supposed, however, that the Polish astronomer attained to our existing amount of knowledge on the subject. Far from it: his ideas were defective in more than one important particular. In order to account for the apparent irregularities in the motions of the planets, as seen from the Earth, he upheld theories which subsequent advances in the science showed to be unnecessary and to rest on no substantial basis. Amongst other things he retained the theory of Epicycles. The ancients considered that the planetary motions must be effected uniformly and in circles, because uniform motion appeared the most perfect kind of motion, and a circle the most perfect and most noble kind of curve. There is at any rate a reverential spirit in this idea which, notwithstanding our enlightenment, we need not despise. Copernicus announced his system in a treatise entitled *De Revolutionibus Orbium cœlestium*, the actual publication of which, in 1543, he only just lived to see, for he died the same year; for him this was perhaps fortunate rather than otherwise, because the work was condemned by the Papal 'Congregation of the Index.' Had it been possible for the reverend gentlemen who formed that body to have got the author within their clutches, it is more than likely that he would have suffered as well as his book; as did Galileo after him.

Fig. 43.



THE TYCHONIC SYSTEM.

Tycho Brahe was the last great astronomer who ventured on any original speculations in this field. Influenced either by *boná fide* scruples resulting from an erroneous interpretation of certain passages in Holy Scripture, or it may be, simply by a desire to perpetuate his name, he chose to regard the Earth as immoveable, and occupying the centre of the system: the Moon as revolving immediately round the Earth:

and, exterior to the Moon, the Sun doing the same thing—the various planets revolving round the latter as solar satellites.

Kepler and Newton finally set matters right by perfecting the Copernican system, and so negativing all the others; yet down to quite recent times there have survived on the part of utterly ignorant people remnants of disbelief (real or professed) in the Copernican system, but even the most cursory examination of these remnants would be most unprofitable.

Fig. 44.

THE HOUSE AT WOOLSTHORPE, LINCOLNSHIRE, IN WHICH NEWTON WAS BORN, SHOWING THE SUNDIALS HE MADE WHEN A BOY.

*** *One of these dials was taken out of the wall about* 1844, *and presented to the Royal Society.*

CHAPTER III.

VULCAN (?).

Le Verrier's investigation of the orbit of Mercury.—Narrative of the Discovery of Vulcan.—Le Verrier's interview with M. Lescarbault.—Approximate elements of Vulcan.—Concluding note by Le Verrier.—Observations by Lummis at Manchester.—Instances of Bodies seen traversing the Sun.—Hind's opinion.—Alleged Intra-Mercurial planets discovered in America by Watson and Swift on July 29, 1878.

BEFORE entering upon the story of the supposed discovery of a new planet to which this name has been given, a brief prefatory statement seems necessary.

M. Le Verrier, having conducted an investigation into the theory of the orbit of Mercury, was led to the conclusion that a certain error in the assumed motion of the perihelion could only be accounted for by supposing the mass of Venus to be at least $\frac{1}{10}$ greater than was commonly imagined, or else that there existed some unknown planet or planets, situated between Mercury and the Sun, capable of producing a disturbing action. In laying his views before the scientific world in the autumn of 1859[a], Le Verrier suggested the latter theory as a probable solution of the difficulty[b].

On these views being made public, a certain M. Lescarbault, a physician at Orgères, in the Department of Eure-et-Loire, France, came forward and stated that on March 26 in that year (1859), he had observed the passage of an object across the Sun's

[a] *Compt. Rend.*, vol. xlix. p. 379. 1859.

[b] Objections to this theory are stated in detail by Newcomb in *Astron. Papers for use of Amer. Naut. Almanack*, vol. i. p. 474. Washington, 1882.

disc which he thought might be a new planet, but which he did not like to announce as such until he had obtained a confirmatory observation; he related in writing the details of his observation, and Le Verrier determined to seek a personal interview with him.

The following account of the meeting will be read with interest.

"On calling at the residence of the modest and unobtrusive medical practitioner, he refused to say who he was, but in the most abrupt manner, and in the most authoritative tone, began, 'It is then you, Sir, who pretend to have observed the intra-Mercurial planet, and who have committed the grave offence of keeping your observation secret for nine months. I warn you that I have come here with the intention of doing justice to your pretensions, and of demonstrating either that you have been dishonest or deceived. Tell me then, unequivocally, what you have seen.' The doctor then explained what he had witnessed, and entered into all the particulars regarding his discovery. On speaking of the rough method adopted to ascertain the period of the first contact, the astronomer inquired what chronometer he had been guided by, and was naturally enough somewhat surprised when the physician pulled out a huge old watch with only minute hands. It had been his faithful companion in his professional journeys, he said; but that would hardly be considered a satisfactory qualification for performing so delicate an experiment. The consequence was, that Le Verrier, evidently now beginning to conclude that the whole affair was an imposition or a delusion, exclaimed, with some warmth, 'What, with that old watch, showing only minutes, dare you talk of estimating seconds? My suspicions are already too well founded.' To this Lescarbault replied, that he had a pendulum by which he counted seconds. This was produced, and found to consist of an ivory ball attached to a silken thread, which, being hung on a nail in the wall, is made to oscillate, and is shown by the watch to beat very nearly seconds. Le Verrier is now puzzled to know how the number of seconds is ascertained, as there is nothing to mark them; but Lescarbault states that with him there is no difficulty whatever in this, as he is accustomed 'to feel pulses and count their pulsations,' and can with ease carry out the same principle with the pendulum. The telescope is next inspected, and pronounced satisfactory. The astronomer then asks for the original memorandum, which, after some searching, is found 'covered with grease and laudanum.' There is a mistake of four minutes on it when compared with the doctor's letter, detecting which, the *savant* declares that the observation has been falsified. An error in the watch regulated by sidereal time accounts for this. Le Verrier now wishes to know how the doctor managed to regulate his watch by sidereal time, and is shown the small telescope by which it is accomplished. Other questions are asked, to be satisfactorily answered. The doctor's rough drafts of attempts to ascertain the distance of the planet from the Sun 'from the period of four hours which it required to describe an entire diameter' of that luminary are produced, chalked on a board. Lescarbault's method, he being short of paper, was to make his calculations on a plank, and make way for fresh ones by planing them off. Not being a mathematician, it may be remarked he had not succeeded in ascertaining the distance of the planet from the Sun.

"The end of it all was, that Le Verrier became perfectly satisfied that an intra-Mercurial planet had been really discovered. He congratulated the medical practitioner upon his discovery, and left with the intention of making the facts thus obtained the subject of fresh calculations [c]."

In March or April, 1860, it was anticipated that the planet would again pass across the Sun, which was carefully scrutinised by different observers on several successive days, but no trace of it was obtained then, and in a certain sense Lescarbault's observation continues unconfirmed. However, this proves nothing, and many are prepared to regard the existence of this planet as a *fact*, to be fully demonstrated on some future occasion.

The following approximate elements were calculated by Le Verrier from Lescarbault's rough observations:—

Longitude of ascending node	=	12° 59′
Inclination of orbit	=	12° 10′
Semi-axis major (⊕ = 0)	=	0·143
Daily heliocentric motion	=	18° 16′
Period	=	$19^d\ 17^h$
Mean distance	=	13,082,000 miles.
Apparent diameter of ☉ from Vulcan	=	3° 36′
Do. do. do. (⊕ = 1)	=	6·79
Greatest possible elongation	=	8°

The application of Kepler's third law yields, as has already been shown, a result sufficiently consistent with the results in the cases of the other planets to demand attention; but, as will now be seen, some additional evidence can be adduced as to the reality of the discovery, much as it has been called in question.

On March 20, 1862, Mr. Lummis, of Manchester, was examining the Sun's disc, between the hours of 8 and 9 A.M., when he was struck by the appearance of a spot possessed of a rapid proper motion. He called a friend's attention to it, and both remarked its sharp *circular* form. Official duties most unfortunately interrupted him, after following it for 20^m; but he had not the slightest doubt about the matter. The apparent diameter was estimated to be about 7″, and in the 20^m it moved over about 12′ of arc. The telescope employed was 2¾ inches in aperture,

[c] Epitomised from the *North British Review*, vol. xxxiii. pp. 1–20, August, 1860. A full account will also be found in *Cosmos*, vol. xvi. pp. 22–8, 1860; see also *Cosmos*, same vol. pp. 50–6.

and was charged with a power of 80. Mr. Lummis communicated with Mr. Hind on the subject of what he had seen; and the latter, by the aid of the diagram sent, determined that 12′ was too great an estimate of the arc traversed by the spot in the time, and that 6′ would be a nearer value [d].

Two French calculators deduced elements from Lummis's observations: the orbits which they obtained, though necessarily very imperfect, are fairly in accord both with each other, and with Le Verrier's earlier orbit.

The first result is adopted from Valz's elements, the second from Radau's.

		I.		II.
Longitude of ascending node	=	2° 52′	...	—
Inclination of orbit...	=	10° 21′	...	—
Semi-axis major (⊕ = 1·0)...	=	0·132′	...	0·144
Daily heliocentric motion	=	20° 32′	...	18° 5′
Period	=	$17^d\ 13^h$	...	$19^d\ 22^h$
Mean distance in miles	=	12,076,000	...	13,174,000

From the heliocentric position of the nodes, it appears that transits can only occur between March 25 and April 10 at the descending, and between September 27 and October 14 at the ascending node.

Instances are not wanting of observations of spots of a planetary character passing across the Sun which may turn out to have been transits of Vulcan [e]. The following are a selection of these instances.

On October 10, 1802, Fritsch, at Magdeburg, saw a round spot pass over the Sun. In 3^m it had moved 2′, and after a cloudy interval of 4^h had disappeared.

On October 9, 1819, Stark, at Augsburg, saw a well-defined and truly circular spot, about the size of Mercury, which he could not find again in the evening.

[d] *Month. Not.*, vol. xxii. p. 232. April 1862. Lummis's observations were very severely criticised by Prof. C. H. F. Peters, who claimed to have identified Lummis's "planet" beyond question with a particular Sun-spot recorded by himself in America and by Spörer in Europe. (*Ast. Nach.*, vol. xciv. No. 2253, April 16, 1879.) Certainly Peters's argument is strong.

[e] *Month. Not.*, vol. xx. p. 100. Jan. 1860; also pp. 192–4. March, 1860; Webb, *Celest. Objects*, p. 40.

On October 2, 1839, Decuppis, at Rome, saw a perfectly round and defined spot moving at such a rate that it would cross the Sun in about 6 hours[f].

On October 11, 1847, Schmidt saw a small black point rapidly pass across the Sun.

On March 12, 1849, Lowe and Sidebotham watched for half an hour a small round black spot traversing the Sun.

On October 14, 1849, Schmidt saw a black body, about 15″ in size, pass very rapidly from East to West before the Sun. "It was neither a bird nor an insect."

In the works whence these instances are cited, others are given; but, though suspiciously suggestive of planets, the dates do not come within the necessary limits for them to have been apparitions of Vulcan, so it is not worth while to transcribe them; but nevertheless they are interesting, and worthy of attention[g].

Fig. 45 will be useful, if for no other purpose, as a warning to observers not to jump too hastily at conclusions as to what they see with their telescopes. On November 30, 1880, M. Ricco at Palermo, whilst making his customary daily observations of Sun-spots with a telescope of 3½ inches aperture, saw a swarm of black bodies slowly traverse the Sun's disc. He thought at first that he had the singular good fortune to be gazing on a shower of meteors, but sustained attention revealed the fact that the objects seen were evidently birds with wings. Subsequent consultation with certain zoologists rendered it tolerably clear that what M. Ricco saw was a swarm of cranes. Some calculations, the details of which need not be gone into here, imply that they were flying at an elevation of 5¾ miles[h].

It is right here to state that M. Liais asserts that being in Brazil he was watching the Sun during the period in which Lescarbault professes to have seen the black spot, and that he is

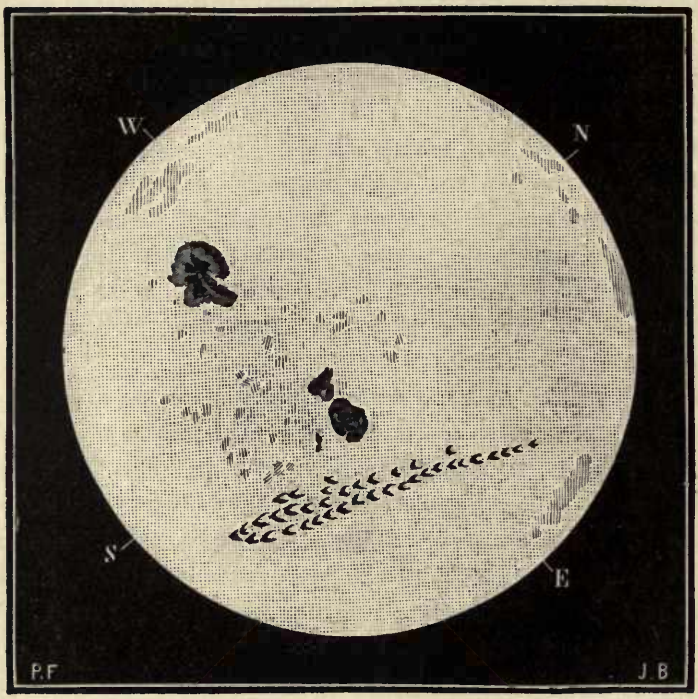
[f] *Comptes Rendus*, vol. ix. p. 809. 1839.

[g] For an exhaustive summary of all the recorded observations of black objects seen on the Sun, see the Rev. E. Ledger's *Lecture on Intra-Mercurial Planets*, 8vo. Cambridge, 1879.

[h] *L'Astronomie*, vol. vi. p. 66. Feb. 1887.

positively certain that nothing of the kind was visible, though the telescope he employed was considerably more powerful than that of the French physician. He adds that parallax will not explain the discrepancy[1]. There is, however, in Liais's paper

Fig. 45.



FLIGHT OF CRANES SEEN CROSSING THE SUN AT PALERMO. NOV. 30, 1880.

a malicious bitterness of tone, presumably intended to annoy Le Verrier, which greatly impairs the value of the writer's testimony.

Though it is the fashion to repudiate the reality of Vulcan's existence, yet it is scarcely prudent to dogmatise on the subject as some have done, considering that an astronomer of Hind's experience leans to the affirmative side. He says:—

"It is a suspicious circumstance that the elements as regards the place of the node, or point of intersection of the orbit with the ecliptic, and its inclination thereto, as

[1] *Ast. Nach.*, vol. liv. No. 1281. Nov. 1, 1860.

worked out by M. Valz of Marseilles, from the data I deduced from a diagram forwarded to me by Mr. Lummis, are strikingly similar to those founded by M. Le Verrier upon the observations, such as they were, of Dr. Lescarbault. It is true if the place of the node and inclination were precisely as given by this astronomer, the object which was seen upon the Sun's disc on the 26th of March could not have been projected upon it as early as the 20th of March. But, considering the exceedingly rough nature of the observations upon which he had to rely, perhaps no stress need be placed upon the circumstance. Now the period of revolution assigned by M. Le Verrier from the observations of 1859 was 19·70 days. Taking this as an approximate value of the true period, I find, if we suppose 57 revolutions to have been performed between the observations of Dr. Lescarbault and Mr. Lummis, there would result a period of 19·81 days. On comparing this value with the previous observations in March and in October, when the same object might have transited the Sun at the opposite node, it is found to lead to October 9, 1819, as one of the dates when the hypothetical planet should have been in conjunction with the Sun. And on this very day Canon Stark has recorded the following notable observation,—'At this time there appeared a black, well-defined nuclear spot, quite circular in form, and as large as Mercury. This spot was no more to be seen at 4.37 P.M., and I found no trace of it later on the 9th, nor on the 12th, when the Sun came out again.' The exact time of this observation is not mentioned, but appears likely to have been about noon, one of Stark's usual hours for examining the solar disc. Hence I deduce a corrected period of 19·812 days."

In the communication from which this is taken[k] Hind throws out suggestions for a scrutiny of the Sun at certain dates. It must be admitted that the scrutiny took place and that no planet was found, and here the matter rests.

Notwithstanding, however, the strong negative evidence then existing against the existence of Lescarbault's planet Vulcan, Le Verrier, in December 1874, re-iterated his announcement that the orbit of Mercury is perturbed to an extent rendering it necessary to augment the movement of the perihelion. He put the amount at 31″ in a century. "The consequence" (he said) "is very clear. There is, without doubt, in the neighbourhood of Mercury, and between that planet and the Sun, matter hitherto unknown. Does it consist of one, or several small planets? or of asteroids, or even of cosmic dust? Theory cannot decide this point[l]."

Le Verrier died in 1877, and the question had in great measure gone to sleep, when some observations made on the occasion of the eclipse of the Sun of July 29, 1878, brought the whole

[k] Letter in the *Times*, Oct. 19, 1872.
[l] *Compt. Rend.*, vol. lxxix. p. 1424. 1874.

matter again before the scientific world, though not precisely in the same shape.

The total eclipse in question was visible over a large part of the western regions of North America. Two of the many American observers, Professor J. C. Watson and Mr. L. Swift, applied themselves to the task of searching for Intra-Mercurial planets, and with what result we shall now see.

Professor Watson's observations, as described by himself, shall first be set out in full:—

"As soon as the total phase began, I commenced a systematic sweep for objects visible near the Sun. From my previous experience in work of this character I had determined not to undertake to sweep over too much space. Accordingly, I confined my search to a region of about 15° in Right Ascension, and $1\frac{1}{2}$° in breadth. I had previously committed to memory the relative places of stars near the Sun down to the seventh magnitude, and the chart of the region was placed conveniently in front of me for ready reference whenever required. Before the totality began, I examined the regions distant from 8° to 15° on the E. side, and also on the W. side of the Sun, without finding any stars. As soon as the total phase had begun I placed the Sun in the middle of the field and began a sweep by moving the telescope slowly and uniformly towards the E. Then I retraced the path thus examined, moved the telescope one field further S., and again swept out and back over a distance of about 8°. In the first of these sweeps I saw δ Cancri and other known stars. Then I placed the Sun again in the field and swept in the same manner towards the W. Between the Sun and θ Cancri, and a little to the S., I saw a ruddy star whose magnitude I estimated to be $4\frac{1}{2}$. It was fully a magnitude brighter than θ Cancri, which I saw at the same time, and it did not exhibit any elongation, such as might be expected if it were a comet in that position. The magnifying power was 45 and the definition excellent. My plan did not provide for any comparison differentially with a neighbouring star by micrometric measurement, and hence I only noticed the relation of the star to the Sun and θ Cancri. Its position I proceeded at once to record on my circles in the manner I have described; and I recorded also the chronometer time of observation. This star was denoted by *a*. Previously to the commencement of the total phase I had recorded a place of the Sun in the same manner, which I designated by S_1. Having made the record I assured myself that the pointing of the telescope had not been disturbed in the least, and I continued the search, sweeping out to about 8° W. from the Sun. Then I went back to the Sun, moved the telescope nearly one field S., and swept out again towards the W. In this sweep I came across a bright star, also ruddy in appearance, which arrested my attention, and for fear that the Sun might reappear before I could make an examination of its surroundings, I determined to make a record of its place upon my circles. This I next proceeded to do, and just as I had completed the record the Sun reappeared. This object was designated by *b*...

"On September 15 I examined, with the same telescope and magnifying power used in the eclipse observations, the stars in this part of Cancer, with the moon in the western sky and the bright twilight in the E., so as to obtain as nearly as possible the conditions of sky-illumination which existed at the time of the eclipse. Having a very distinct recollection in respect to the brilliancy of the stars which I saw, and by observing when the approaching daylight had reduced the light of certain stars which were E. of the Sun at the time of the total eclipse, so as to be just visible in the telescope as they were then, I have been enabled to form a still more definite opinion of the relative brilliancy of θ Cancri, the two new objects which I observed, and ζ Cancri. The fainter of the two planets, that near θ Cancri, was certainly brighter than ζ Cancri, and much more than a magnitude brighter than its neighbouring star. I am inclined to think that (*a*) should be classed as a good 4th magnitude, and that (*b*) should be classed as a 3rd magnitude, at the time of the observations on July 29. It is, of course, impossible to determine from these observations the planetary character of the stars observed. They did not exhibit such appearances as might be expected if they were comets near the sun ; and since theory demonstrates the existence of such planets, I feel warranted in expressing the belief that the foregoing observations give places of two Intra-Mercurial planets. It is true that they were not so bright as might be expected if they were of size sufficient alone to account for the outstanding perturbations of Mercury, but it should be remembered that this expectation is based upon the assumption that the reflecting power of the surfaces of these planets is the same, or nearly the same, as that of Mercury. Now we know from actual observations that the intrinsic brilliancy of Mercury is scarcely $\frac{1}{8}$th that of Venus when reduced to the same distance, and hence we cannot safely assume that the Intra-Mercurial planets must have the same relative brilliancy that they would have if their surfaces could reflect the light to the same extent as that of Mercury. I feel assured that by suitable devices these planets may be observed in full daylight near their elongations. Whether they are identical or not with moving spots which have been seen on the Sun's surface at different times it does not yet seem possible to determine [m]."

Swift's account of his work runs as follows:—

"I reluctantly broke away from the wondrous scene [the Corona], and immediately essayed the well-nigh hopeless task which I had chosen—the finding of an Intra-Mercurial planet. To my dismay I soon found that I had forgotten to untie the string holding the pole in place, and this prevented all search E. of the Sun, as if I attempted a move in that direction the lower end would plunge into the ground and against the little tufts of buffalo-grass. It is, perhaps, to this circumstance alone that I owe the discovery of Vulcan some 5 minutes after its detection by Professor Watson, totality having terminated at his station before its commencement at mine.

"Almost the first sweep made to the westward of the Sun I ran across 2 stars presenting a very singular appearance, each having a red round disc and being free from twinkling. I at once resolved to observe these with great care. Time was precious and yet 6 questions demanded an immediate answer, viz :

1. What were their distances from the Sun ?
2. What from each other ?
3. What direction from the Sun ?
4. What from each other ?

[m] *Washington Observations*, 1876, App. III, "Reports on Total Solar Eclipses," pp. 119–23.

5. What the magnitude of each?
6. What stars were they?

"My telescope, though equatorially mounted, had no circles, and consequently no measurements were possible, but I endeavoured to be as accurate as existing circumstances would allow. My estimated answers were as follows:—

1. About 3° from Sun's centre to midway between the stars.
2. About 8′.
3. South of West.
4. They were both on a line with the Sun's centre.
5. Equal, and of the 5th magnitude.
6. Probably, one was Theta Cancri; the other an Intra-Mercurial planet.

"After completing these observations I resumed the quest, sweeping again southerly and W., but my fettered telescope behaved badly, and no regularity in the sweeps could be maintained, and I was surprised to find, in a few seconds, 2 stars in the field answering, in every particular, to the above description, and, sighting along the top of the tube on the outside, as in the first instance, I found they were the same objects. Again, I went through with the above comparisons, though I devoted only about one-fourth of the time given on the first occasion. Finding no necessity for modifying any of the above estimates, I, for the third time, renewed my sweeps, this time nearly along the ecliptic, though I feared to go too far to the W. lest I might not be able to get the glass back again to make a third and final observation of them, and also of the closing scenes of totality. I could place no dependence on the sweeps, and after a few seconds more (though it seemed longer) had them again in the field, This proved to be the last time. I again asked myself the already twice repeated questions, but found no appreciable change had taken place between the first and third observations—an interval of probably 1¼ minutes. Again I searched, but saw nothing, and, recollecting that I had no more time to spare, I endeavoured to refind the stars for a last observation, but unfortunately a small cloud (the only one within 50°) passed over them, and I was unsuccessful. I saw no stars but these 2, not even Delta, so near the Eastern limb of the Sun. As soon as totality was ended, I recorded in my note-book as follows: 'Saw 2 stars about 3° S.W. of Sun, apparently of 5th magnitude some 12′ apart, pointing towards Sun. Red.' On my homeward journey the thought occurred to me that the distance between the stars was, according to memory, a little greater than half that between Mizar and Alcor, whatever that might be. Consulting 'Webb's Celestial Objects,' I found they were but 11½′ apart, which would make the distance of the two stars not to exceed 8′, instead of 12′, as hastily written at the time. While scanning them, I asked the mental question, 'What star looks at night to the naked eye as bright as do these through the telescope now?' Instantly, I answered 'The Pole-star.' That one was Theta Cancri is in the highest degree probable, and the other a planet is beyond all question, for on the morning of the 10th instant I observed Theta robbed of the companion I saw during the eclipsed Sun [n]."

These discoveries were hotly canvassed and their authenticity directly called in question, but not, I think, on fair or adequate grounds. It will be worth while, however, to examine the details

[n] *Washington Observations*, 1876, App. III, "Reports on Total Solar Eclipses," p. 229.

of the controversy. Watson's idea of what he saw may be thus expressed. He first noticed a star which he thought was δ Cancri, then θ Cancri, and near to θ an unknown body which he designated *a*; then a second strange object (designated *b*) which he saw near to the place in which he expected to find ζ Cancri, the discovery of which, because he presumed it to be ζ Cancri, led him to search no further in that part of his field of view.

The theory of the hostile critic, Professor C. H. F. Peters [o], is, that *a* was θ Cancri and *b* was ζ Cancri, and that some error in Watson's circles led to both his observations being vitiated in the same direction and to the same extent. This insinuation was however warmly repudiated by Watson [p]. Peters dealt with Swift's record in a still more simple fashion: charged him with describing objects which he did not see at all, and implied that he concocted his alleged discovery after the publication of a telegram from Watson! Swift's reply to all this was as dignified as it was emphatic [q].

Swift's observations seem, in part at least, irreconcileable with Watson's, and if we assume the reality of Swift's 2 planets then Watson's *a* is a 3rd object and perhaps his *b* a 4th, so that in point of fact the 2 observers in question would seem to have discovered between them 4 Intra-Mercurial planets, which is in the highest degree improbable. Here the matter rests [r], except that the observers of the Total Solar Eclipse of May 6, 1883, say that they saw no object which could have been a planet, although specially searching for the purpose of finding a planet, if possible.

[o] *Ast. Nach.*, vol. xciv. No. 2253, Apr. 16, 1879.

[p] *Ast. Nach.*, vol. xcv. No. 2263, June 17, 1879.

[q] *Ast. Nach.*, vol. xcv. No. 2277, Sept. 17, 1879.

[r] A summary review by Colbert of the evidence which appears in the *Sidereal Messenger* (U.S.), vol. vi. p. 196 (May, 1887), seems to make the reality of *some* discovery perfectly clear; on the contrary side, reference may be made to remarks by Prof. Young in *Sid. Mess.*, vol. vi. p. 21, Jan. 1887.

CHAPTER IV.

MERCURY. ☿

Period, &c.—Phases.—Physical Observations by Schröter, Sir W. Herschel, Denning, Schiaparelli and Guiot.—Determination of its Mass.—When best seen.—Acquaintance of the Ancients with Mercury.—Copernicus and Mercury.—Le Verrier's investigations as to the motions of Mercury.—Tables of Mercury.

MERCURY is, of the old planets[a], the one nearest to the Sun, round which it revolves in $87^d\ 23^h\ 15^m\ 43{\cdot}91^s$, at a mean distance of 35,958,000 miles. The eccentricity of the orbit of Mercury amounting to 0·205, the distance may either extend to 43,347,000 miles, or fall as low as 28,569,000 miles. The apparent diameter of Mercury varies between 4·5″ in superior conjunction, and 12·9″ in inferior conjunction: at its greatest elongation it amounts to about 7″. The real diameter may be about 3008 miles or less[b]. The compression, or the difference between the polar and equatorial diameters, has usually been considered to be too small to be measureable, but Dawes, in 1848, gave it at $\frac{1}{29}$.

Mercury exhibits *phases* resembling those of the Moon. At its greatest Elongation (say W.) half its disc is illuminated, but as it approaches Superior Conjunction the breadth of the illuminated part increases, and its form becomes *gibbous*; and ultimately, when in Superior Conjunction, circular: at and near this point the planet is lost in the Sun's rays, and is invisible.

[a] In case it should be thought that these accounts of the planets are deficient in statistical data, it may here be remarked that they are intended to be read in connexion with the tabulated statistics in the Appendix of this volume, as it has been thought for several reasons undesirable to encumber the Text of Book I. with too many figures.

[b] An American observer, D. P. Todd, in 1880, put it at 2971 miles.

On emerging therefrom the gibbous form is still apparent, but the gibbosity is on the opposite side, and diminishes day by day till the planet arrives at its greatest Elongation E., when it again appears like a half-moon. Becoming more and more crescented, it approaches the Inferior Conjunction; and having passed this, the crescent (now on the opposite side) gradually augments until the planet again reaches its greatest W. Elongation.

Owing to its proximity to the Sun, observations on the physical appearance of Mercury are obtained with difficulty, and are therefore open to much uncertainty. The greatest possible elongation of the planet not exceeding 27° 45′ (and it being in general less), it can never be seen free from strong sunlight [c], under which conditions it may occasionally be detected with the naked eye during $1\frac{1}{2}^h$ or so after sunset in the spring (E. Elongation) and before sunrise in the autumn (W. Elongation), shining with a pale rosy hue. With the aid of a good telescope equatorially mounted, Mercury can frequently be found in the daytime.

Mercury has not received much attention from astronomers in the present day, and the observations of Schröter, at Lilienthal, and those of Sir W. Herschel, are the main sources of information. The former observer and his assistant Harding obtained what they believed to be decisive evidence of the existence of high mountains on the planet's surface: one in particular, situated in the Southern hemisphere, was supposed to manifest its presence from time to time, in consequence of the Southern horn, near Inferior Conjunction, having a truncated appearance, which it was inferred might be due to a mountain arresting the light of the Sun, and preventing it from reaching as far as the cusp theoretically extended [d]. The extent of this truncature would serve to determine the height of the mountain occasioning it,

[c] When Mercury's Elongation is the greatest possible, the planet's position is (in England) S. of the Sun, and therefore the chances of seeing it are not so good as when an Elongation coincides with a more Northerly position, albeit the Elongation is less considerable. The greatest possible Elongation is a W. one which happens at the beginning of April. The least (17° 50′) an Elongation (also W.) which happens at the end of September.

[d] This has also been seen by Noble (*Ast. Register*, vol. ii. p. 106. May 1864).

which has been set down at 10·7 miles, an elevation far exceeding, absolutely, anything we have on the Earth, and in a still more marked degree relatively, when the respective diameters of the 2 planets are taken into consideration. Schröter, pursuing this inquiry, announced that the planet rotated on its axis in $24^h\ 5^m\ 48^s$. Sir W. Herschel was unable to confirm these results either in whole or even in part[e], and the alleged period of rotation we are justified in considering to be wholly a myth, so far at least as *observation* is concerned. Schiaparelli considers Schröter's rotation-period to be "very far from the truth."

Denning and Schiaparelli think that Mercury is more easy to observe than Venus, and that its physical aspect resembles that of Mars more than any other planet. Schiaparelli's most successful observations have been obtained with the planet near Superior Conjunction, when the defect of the diameter was compensated for by the fact that nearly the whole disc was to be seen. In such position it is then more strongly illuminated than at epochs of quadrature.

Denning's observations above alluded to were made on November 6, 7, 9, 10, 1882, with a 10-inch reflector, power 212. He says:—

"Some dark, irregular spots were distinctly seen upon the planet; also a small brilliant spot, and a large white area between the E. N. E. limb and terminator. The south horn was also much blunted, especially on the two first dates of observation. My results have led me to infer that the markings upon Mercury are far more decided and easily discernible than those of Venus; and that the aspect of the former planet presents a close analogy to the physical appearance of Mars. The rotation-period given by Schröter seemed too short to conform with the relative places of the markings as I delineated them on the several dates referred to[f]."

Denning elsewhere[g] states that the large white area in question had in its centre a very brilliant small spot, "with luminous veins or radiations extending over the whole area."

[e] But it must not be forgotten in this connection that Sir William was never amicably disposed towards Schröter. (See Holden's *Life and Works of Sir W. Herschel*, p. 91.)

[f] *Month. Not.*, vol. xliii. p. 301. March 1883.

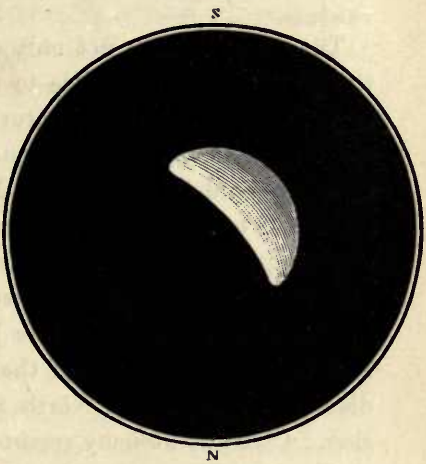
[g] *Observatory*, vol. vii. p. 40. Feb. 1884.

Figs. 46–47 represent the planet Mercury as seen before sunrise in the autumn of 1885.

The observer remarked the truncated form of both of the horns on the former occasion, and of the Southern horn on the latter occasion. He makes no mention of any shading or spots.

Fig. 46.

Fig. 47.



MERCURY.

SEPT. 17, 1885, AT 5^h 25^m A.M. (*Guiot.*) SEPT. 22, 1885, AT 5^h 30^m A.M. (*Guiot.*)

The phases of Mercury are noticeable, as it has sometimes been found that the breadth of the illuminated portion is less than according to calculation it should be. This does not rest on the testimony of Schröter alone, but is supported by Beer and Mädler, from an observation made on September 29, 1832.

Mercury is not known to be possessed of an atmosphere; and if one exists, it must be very insignificant. Sir W. Herschel, contradicting Schröter and Harding, pronounced against its existence, and Zöllner from photometric experiments on reflection from the surface of Mercury generally, thinks that there cannot be any atmosphere sufficient to reflect the light of the Sun. [But see Book II., Chap. X., "Transits," *post.*]

Mercury is, as far as we know, attended by no satellite, and the determination of its mass is a difficult and uncertain problem. However, the small comet of Encke has furnished the means of learning something, and from considerations based on the disturbances effected in the motion of this comet by the action of Mercury, it has been calculated by Encke that the mass of the latter is $\frac{1}{4865751}$ that of the Sun. Le Verrier gives $\frac{1}{3000000}$; Littrow $\frac{1}{2025810}$; and Mädler $\frac{1}{4870333}$; but Newcomb has fixed on a fraction widely different from all these, namely, $\frac{1}{7500000}$.

The ancients were not only acquainted with the existence of this planet [h], but were able to ascertain with considerable accuracy its period, and the nature of its motions in the heavens. "The most ancient observation of this planet that has descended to us is dated in the year of Nabonassar 494, or 60 years after the death of Alexander the Great, on the morning of the 19th of the Egyptian month *Thoth*, answering to November 15 in the year 265 before the Christian era. The planet was observed to be distant from the right line joining the stars called β and δ in Scorpio, one diameter of the Moon; and from the star β two diameters towards the North, and following it in Right Ascension. Claudius Ptolemy reports this and many similar observations extending to the year 134 of our era, in his great work known as the *Almagest* [i]."

We have also observations of the planet Mercury by the Chinese astronomers, as far back as the year 118 A.D. These observations consist, for the most part, of approximations (appulses) of the planet to stars. Le Verrier tested many of these Chinese observations by the best modern tables of the movements of Mercury, and found, in the greater number of cases, a very satisfactory agreement. Thus, on June 9, 118 A.D. the Chinese observed the planet to be near the cluster of stars usually termed Præsepe, in the constellation Cancer; calculation from modern theory shows that on the evening of the day mentioned Mercury was less than 1° distant from that group of stars.

"Although the extreme accuracy of observations at the present

[h] Pliny, *Hist. Nat.*, lib. ii. cap. 7; Cicero, *De Naturâ Deorum*, lib. ii. cap. 20.

[i] Hind, *Sol. Syst.*, p. 23.

day renders it unnecessary to use these ancient positions of the planets in the determination of their orbits, they are still useful as a check upon our theory and calculations, and possess, moreover, a very high degree of interest on account of their remote antiquity[k]."

La Place said:—"A long series of observations were doubtless necessary to recognise the identity of the two bodies, which were seen alternately in the morning and evening to recede from and approach the Sun: but as the one never presented itself until the other had disappeared, it was finally concluded that it was the same planet which oscillated on each side of the Sun." Arago considered that "This remark of La Place's explains why the Greeks gave to this planet the two names of Apollo, the god of the day, and Mercury, the god of the thieves, who profit by the evening to commit their misdeeds."

The Greeks gave Mercury the additional appellation of ὁ Στίλβων, "the Sparkling One." When astrology was in vogue, it was always looked upon as a most malignant planet, and was stigmatised as a *sidus dolosum.* From its extreme mobility chemists adopted it as the symbol for quicksilver.

It is rather difficult, in a general way, to see Mercury, and Copernicus, who died at the age of 70, complained in his last moments that, much as he had tried, he had never succeeded in detecting it; a failure due, as Gassendi supposes, to the vapours prevailing near the horizon on the banks of the Vistula where the illustrious philosopher lived. An old English writer, of the name of Goad, in 1686, humorously termed this planet "a squirting lacquey of the Sun, who seldom shows his head in these parts, as if he were in debt."

When speaking on a previous page (see p. 75 *ante*) of the planet Vulcan, mention was made of Le Verrier's conclusion that the motion of Mercury's perihelion was influenced by some unknown cause of disturbance. Not to discuss this matter at length here it may be stated that Newcomb has given it as his opinion that the discordance between the observed and theoretical motions

[k] Hind, *Sol. Syst.*, p. 23.

of the perihelion of Mercury first pointed out by Le Verrier really exists, and is indeed larger than he supposed[l].

In computing the places of Mercury, the Tables of Baron De Lindenau, published in 1813, were long employed, but they are now superseded by the more accurate Tables of Le Verrier[m].

[l] *Astron. Papers for use of Amer. Naut. Almanack*, vol. i. p. 472; 1882.

[m] *Annales de l'Obs. de Paris, Mémoires*, vol. v. p. 1; 1859.

CHAPTER V.

VENUS. ♀

Period, &c.—Phases resemble those of Mercury.—Most favourably placed for observation once in 8 years.—Observations by Lihou.—By Lacerda.—Daylight observations.—Its brilliancy.—Its Spots and Axial Rotation.—Suspected mountains and atmosphere.—Its "ashy light."—Phase irregularities.—Suspected Satellite.—Alleged Observations of it.—The Mass of Venus.—Ancient observations.—Galileo's anagram announcing his discovery of its Phases.—Venus useful for nautical observations.—Tables of Venus.

NEXT in order of distance from the Sun, after Mercury, is Venus; which revolves round the Sun in $224^d\ 16^h\ 49^m\ 8^s$, at a mean distance of 67,190,000 miles. The eccentricity of the orbit of Venus amounting to only 0·007, the extremes of distance are only 67,652,000 miles and 66,728,000 miles. This eccentricity is very small. No other planet, major or minor, has an eccentricity so small. The apparent diameter of Venus varies between 9·5″ in Superior and 65·2″ in Inferior Conjunction. At its greatest Elongation its apparent diameter is about 25″. A numerous series of careful observations enabled Main to determine that the planet's diameter (reduced to mean distance) is

Fig. 48.

VENUS NEAR ITS GREATEST ELONGATION.
(*Schröter.*)[a]

[a] Figs. 49–50 are copied, with an unimportant variation, from Pl. xlii of Schröter's *Selenotopographische Fragmente.*

17·55″, subject to a correction of −0·5″ for the effects of irradiation. Stone, from an elaborate discussion of a large series of Greenwich observations, obtained 16·944″, with a probable error of ±0·08″. Tennant in 1874 (during the Transit) obtained, as the mean of 68 measures, 16·9036″ (reduced) with a probable error of 0·0016″ only[b]. The real diameter corresponding to this latter evaluation is about 7500 miles, or, roundly, Venus is a planet almost as large as the Earth. The compression must be small, but Tennant thinks he found traces thereof. Great difficulty must ever remain in clearly detecting it, because the planet's diameter in Superior Conjunction is so small.

Venus exhibits phases precisely identical in character with those of Mercury.

Though under the most favourable circumstances Venus is never farther removed from the Sun than 47° 15′, and is therefore always more or less under the influence of twilight, yet it is difficult to scrutinise this planet for a reason additional to that which obtains with Mercury, namely, its own extreme brilliancy. This is such as to render the planet not unfrequently visible in full daylight and capable of casting a sensible shadow at night. This happened in January 1870, and indeed occurs every 8 years, when the planet is at or near its greatest North latitude and about 5 weeks from Inferior Conjunction. Its apparent diameter is then about 40″, and the breadth of the illuminated part nearly 10″, so that rather less than ¼ of the entire disc is illuminated;

Fig. 49.

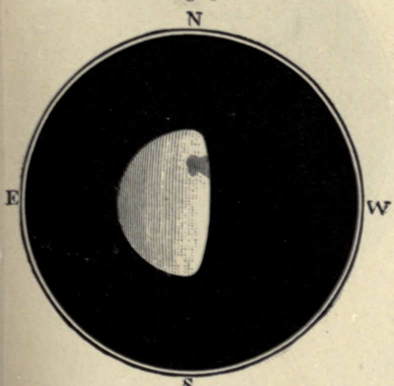
VENUS NEAR ITS INFERIOR CONJUNCTION.
(*Schröter.*)

[b] *Month. Not.*, vol. xxxv. p. 347. May 1875.

but this fraction transmits more light than do phases of greater extent, because the latter occur at greater distances from the Earth. A lesser maximum of brilliancy, due to the same circumstances less favourably carried out, occurs on either side of the Sun at intervals of about 29 months. The planet's angular distance from the Sun on these occasions is rather less than 40° (in the superior part of its orbit); its phase therefore corresponds with the phases of the Moon when 11^d and 17^d old.

Figs. 50–1 are selected from some drawings by Lihou taken in the winter of 1885–6 with a refractor of $4\frac{1}{4}$ inches aperture.

Fig. 50.



Nov. 10, 1885.

Fig. 51.

Dec. 23, 1885.

He makes [c] the following remarks on what he saw:—

Nov. 10, 1885.—"With a telescope of about 4 inches aperture armed with a magnifying power of 100 I was able to distinguish a grey spot in the northern hemisphere. Spots on Venus being very difficult to see with small instruments, this observation merits attention."

Dec. 8, 1885.—"Sky very pure. The light of Venus is so bright as to fatigue the eye, but by making use of a coloured glass I am able to see the limbs sharply defined."

Dec. 16, 1885.—"Sky very pure. The image of Venus is extremely sharp, and the limbs well defined; the northern cusp is sharply pointed, whilst the southern is slightly truncated."

Dec. 23, 1885.—"The northern cusp of Venus is sharply pointed, and the southern cusp slightly truncated."

[c] *L'Astronomie,* vol. v. p. 148, April 1886.

Figs. 52–5 are intended to represent some drawings of Venus made in 1884 by M. Lacerda of Lisbon. Respecting these he writes as follows:—

"Sept. 8, 1884.—The crescent of Venus appears sensibly more narrow towards the North Pole than towards the South Pole. With a magnifying power of 250 I cannot distinguish the Southern spots, which, however, were very visible with a magnifying power of 160. I notice that the Northern hemisphere is brighter than the rest of the planet. A very obscure and elongated spot is visible near the North Pole."

Fig. 52.

Sept. 8, 1884.

Fig. 53.

Sept. 9, 1884.

VENUS.

"Sept. 9, 1884.—There is a very bright thread of light concentric with the Eastern limb of the planet; perhaps some high clouds lying along a maritime shore of Venus. Two large spots are also visible on the crescent; the one, oblong, stretched parallel to the bright spot; the other, almost round, and much smaller, to the North of the first. The Southern horn is always longer than the Northern one. The elongated spot which hollows out the planet near the North Pole continues to be very visible.

M. Lacerda says that on the following morning, Sept. 10, he was unable to distinguish any spots.

His next observation is dated—

"Oct. 8, 1884.—The 2 dark spots have sensibly shifted their positions towards the North. They disclose also a slight movement towards the West. The terminator which seemed shrunk up towards the North Pole is to-day almost perfect; but the Southern horn continues to appear longer and more pointed than the Northern one. The lustre of the planet seems uniform. The dark spot which cut into the crescent near the North Pole is not visible."

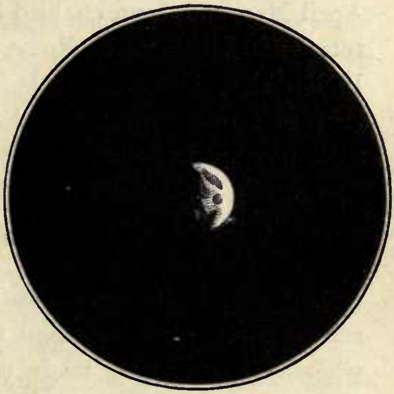
"Oct. 13, 1884.—There is a great depression near the Southern horn. 2 spots are visible on the planet; one to the South; the other, smaller, and to the North; and a third was suspected under the equator, near the illuminated limb and concentric with it. The Northern horn is truncated."

M. Lacerda concludes his observations by remarking that the most favourable time for observing Venus is between ½ an hour before sunrise and 1 hour after sunrise. He adds that he was never able to see any spots when the planet was in the west, at or near the time of sunset[c].

Fig. 54.

Oct. 8, 1884.

Fig. 55.



Oct. 11, 1884.

VENUS.

Observations of Venus in the daytime were made at a very early period; the following are the dates of a few instances: 398 A.D., 984, 1008, 1014, 1077, 1280, 1363, 1715, 1750. "Bouvard has related to me," says Arago, "that General Buonaparte, upon repairing to the Luxembourg, when the Directory was about to give him a fête, was very much surprised at seeing the multitude which was collected in the Rue de Tournon pay more attention to the region of the heavens situate above the palace than to his person or to the brilliant staff which accompanied him. He inquired the cause, and learned that these curious persons were observing with astonishment, although it was

[c] *L'Astronomie*, vol. iii. p. 462, Dec. 1884.

noon, a star, which they supposed to be that of the Conqueror of Italy; an allusion to which the illustrious general did not seem indifferent when he himself with his piercing eyes remarked the radiant body. The star in question was no other than Venus[d]."

The dazzling brilliancy of this planet is such[e] that the daytime is to be preferred for observing it, but under the best of circumstances it is far too tremulous for physical observations to be conveniently made. J. D. Cassini attacked it in 1667, and some ill-defined dusky spots seen on various occasions during April, May, and June, enabled him to assign $23^h\ 15^m$ for its axial rotation. Bianchini, at Rome, in 1726 and 1727, favoured by an Italian sky, observed spots with greater facility: thence he inferred a rotation performed in 24 *days* 8 hours. Cassini's son came forward in defence of his father's observations, and assailed Bianchini's conclusions by alleging that the latter, only seeing Venus for a short time every evening by reason of the Barbarini Palace interrupting his view, and finding the spots night after night nearly in the same position, concluded that the planet had rotated through a very small arc during the previous 24 hours, whereas it had really made one complete rotation and part of a second. After the lapse of 24 days it would exhibit exactly the same portion of its surface, but in the 24-days' interval would really have made 25 revolutions instead of *one*, as Bianchini had supposed. Bianchini's observations thus interpreted imply a period of $23^h\ 2\frac{1}{2}^m$.

Sir W. Herschel, desirous of arriving at some certain knowledge on the subject, devoted much care to the matter; but, failing to see any permanent markings on Venus, he was unable to assign a precise period beyond believing generally that Bianchini's statement was largely in excess of the true amount. Schröter claimed to have seen certain spots which enabled him to deduce a period of $23^h\ 21^m\ 7{\cdot}98^s$, and Di Vico and his colleagues

[d] *Pop. Ast.*, vol. i. p. 701, Eng. ed.

[e] Lord Grimthorpe states that Venus has been experimentally found to be 10 times as bright as the brightest part of the full moon. (*Ast.*, 3rd ed., p. 149.)

at Rome, in 1840–2, rediscovering as they thought Bianchini's markings, assigned a period of $23^h\ 21^m\ 23{\cdot}93^s$.

In spite of the seemingly circumstantial character of these evaluations it cannot be said that astronomers generally are satisfied to accept them, or to think that anything at all conclusive is at present known as to the real duration of Venus's axial rotation.

Sir W. Herschel saw a few transient spots, but his opinion was that they were in the atmosphere, and did not belong to the solid body of the planet. Di Vico, however, professed to have found the spots just as they had been delineated by Bianchini, with one exception. Of the several observers who worked with Di Vico the most successful were those who had most difficulty in catching very minute companions to large stars, the reason of which is obvious. A very sensitive eye, which would detect the spots readily, would be easily overpowered by the light of a brilliant star, so as to miss a very minute one in its neighbourhood.

On Nov. 10, 1885, Lihou saw a gray spot in the Northern hemisphere of Venus as depicted in Fig. 50, *ante*.

Mountains probably exist on Venus, though the testimony on which the statement must rest is not so conclusive as could be desired. In August 1700 La Hire, observing the planet in the daytime near its Inferior Conjunction, perceived in the lower region of the crescent inequalities which could only be produced by mountains higher than those in the Moon. Schröter asserted[f] the existence of several high mountains, in which he was confirmed by Beer and Mädler, but his details as to precise elevation measured by toises must be accepted with great reserve, amongst other reasons because it is doubtful whether his micrometers were of sufficient delicacy. Sir W. Herschel disbelieved him on some points, and attacked him in the *Philosophical Transactions* for 1793[g]: his reply was published in the volume for the year but one after[h]; it was calm and dignified, and vindicated the

[f] *Phil. Trans.*, vol. lxxxii. p. 337. 1792.

[g] *Phil. Trans.*, vol. lxxxiii. p. 202. 1793.

[h] *Phil. Trans.*, vol. lxxxv. p. 117. 1795.

mountains, if not the measurements. Di Vico, at Rome, in April and May 1841, appears to have noticed a surface-configuration akin to that of the Moon; and Lassell, when at Malta in January 1862, observed the same sort of thing. Browning, on March 14, 1868, saw mottlings on the surface of Venus which reminded him of the look of the Moon as seen in a small telescope through a mist. A bluntness of the southern horn, referred to by Schröter, was also seen by the Roman astronomers, and often by Breen subsequently with the Northumberland telescope at Cambridge.

That Venus has an atmosphere is almost certain; that it is of considerable density is likewise an opinion apparently well founded. During the transits of 1761, 1769, and 1874, the planet was observed by several persons to be surrounded by a faint ring of light, such as an atmosphere would account for. Schröter, too, discovered what appeared to him to be a faint crepuscular light extending beyond the cusps of the planet into the dark hemisphere. From micrometrical measures of the space over which this light was diffused he considered the horizontal refraction at the surface of the planet to amount to 30′ 34″, or much the same as that of the Earth's atmosphere. Sir W. Herschel confirmed the discovery as a whole[h], and more recently Mädler, in 1849, was able to do the same with the mere modification of making the amount somewhat greater, or equal to 43·7′. With this the Transit results of 1874 fairly agree; *e.g.*, Prof. C. S. Lyman, 44·5′.[i]

It is quite worth while to dwell upon the observations on which these conclusions rest, for the subject deserves much more telescopic investigation than has hitherto been given to it, and it is one within the reach of many amateurs.

The observations must be made when the planet is very near Inferior Conjunction. Under such circumstances the limb of the planet which is farthest from the Sun is often to be seen illuminated, exhibiting a curved line of light; this is a con-

[h] *Phil. Trans.*, vol. lxxxiii. p. 214. 1793.

[i] Neison suggests that Madler's and Lyman's results must be increased to 54·4′ and 53·5′ respectively, an error having crept in owing to an erroneous formula having been used. (*Month. Not.*, vol. xxxvi. p. 347, June 1876.)

tinuation of the narrow crescent of the planet itself, and the result is, that the planet seems to be surrounded by a complete circle of light. "If only half the globe of the planet were illuminated by the Sun, this appearance could never present itself, as it is impossible for an observer to see more than half of a large sphere at one view. There is no known way in which the Sun can illuminate so much more than the half of Venus as to permit a complete circle of light to be seen, except by the refraction of an atmosphere [k]."

The existence of snow at the poles of Venus has been suspected by Webb and Phillips, but the idea awaits confirmation, though there is no *primâ facie* reason why it should not be well founded; indeed rather the reverse.

A phenomenon analogous to the *lumière cendrée*, or 'ashy light,' of the Moon is well attested in observations of Venus when near Inferior Conjunction, having been first seen by Riccioli on Jan. 9, 1643. Many observers have noticed the entire contour of the planet to be of a dull grey hue beyond the Sun-illumined crescent. Webb used the expression "*the phosphorescence of the dark side*"; this certainly is an objectionable phrase, for phosphorescence notably conveys the idea that some *inherent* light is spoken of, whereas there can be little doubt that refraction and reflection jointly are in some way or other the cause of what is seen in the case of Venus, though it may be difficult at present to specify the precise nature of it [l]. Derham noticed this appearance, and refers to it in his book [m]; and Schröter, Sir W. Herschel, Di Vico, and Guthrie [n] are amongst those that have seen it. Green, Winnecke, Noble, and others have repeatedly seen the unilluminated limb of Venus distinctly *darker* than the back-ground on which it was projected. The most recent observations in detail of this phenomenon are those made by Zenger, at Prague, in Jan. 1883. He speaks in strong terms of

[k] Newcomb, *Popular Astronomy*, p. 293.

[l] The supposition of the existence of some such phenomenon as our Aurora Borealis rests on no foundation.

[m] *Physics and Astro-theology*, vol. ii. book v. ch. 1.

[n] *Month. Not.*, vol. xiv. p. 169. March 1854.

the beauty of the spectacle when seen under favourable circumstances as regards the planet's position and the condition of the Earth's atmosphere. He noticed, and considered the most important point of all, a brownish red ring all round the planet's disc, "more pronounced on the illuminated side than on the dark part of the limb, but of a peculiar coppery hue, the close resemblance of which to the coppery hue the Moon's disc assumes when totally eclipsed was very striking." He goes on to express the opinion that the two appearances owe their origin to precisely similar causes [o].

The peculiarity about Mercury's phases already pointed out (the measured breadth being different from the calculated) obtains also with Venus. At the Greatest Elongations, the line terminating the illumination ought to be straight, as with a Half-Moon, but several observers have found an uncertainty varying between 3^d and 8^d in the first (or last) appearance of the *dichotomisation* (according as to whether it was the E. or the W. Elongation that was in question). Thus, at the Western Elongation of August 1793, Schröter found the terminator slightly concave, and it did not become straight till 8^d after the epoch of Greatest Elongation.

Previous to the present century testimony was not wanting that Venus had a satellite, but nothing has been ascertained about it in recent times, and Webb, with great propriety, called the matter "an astronomical enigma." On Jan. 25, 1672, J. D. Cassini saw, between 6^h 52^m and 7^h 2^m A.M., a small star resembling a crescent, like Venus, distant from the Southern horn on the Western side by a space equal to the diameter of Venus. On Aug. 28, 1686, at 4^h 15^m A.M., the same experienced observer saw a crescent-shaped light East of the planet at a distance of $\frac{3}{5}$ths of its diameter. Daylight rendered it invisible after $\frac{1}{2}$ an hour. On Oct. 23, 1740 (O.S.), Short, the celebrated optician, with 2 telescopes and 4 different powers, saw a small star perfectly defined but less luminous than the planet, from which

[o] Zenger's paper should be consulted by all who wish to study this subject. *Month. Not.*, vol. xliii. p. 331. April 1883.

it was distant 10′ 2″. On 4 different occasions between May 3 and 11, 1761, Montaigne, at Limoges, saw what he believed to be a satellite of Venus. It presented the same phase as the planet, but it was not so bright. Its position varied, but its diameter appeared equal to $\frac{1}{4}$th that of the planet. The following extract is from the *Dictionnaire de Physique*, a French work published in 1789. "The year 1761 will be celebrated in astronomy in consequence of the discovery that was made on May 3 of a satellite circulating round Venus. We owe it to M. Montaigne, member of the Society of Limoges, who observed the satellite again on the 4th and 7th of the same month. M. Baudouin read before the Academy of Sciences of Paris a very interesting memoir, in which he gave a determination of the revolution and distance of the said satellite. From the calculations of this expert astronomer we learn that the new star has a diameter about $\frac{1}{4}$ that of Venus, that it is distant from Venus almost as far as the Moon is from the Earth, that its period is $9^d\ 7^h$, and that its ascending node is in the 22nd degree of Virgo." Wonderfully circumstantial! In March 1764 several European observers, at places widely apart, saw a supposed satellite. Rödkier, at Copenhagen, on March 3 and 4, saw it: Horrebow, with some friends, also at Copenhagen, saw it on the 10th and 11th of the same month, and they stated that they took various precautions to make sure there was no optical illusion. Montbaron, at Auxerre, on March 15, 28, and 29, saw the satellite in sensibly different positions [p].

This is the plaintiff's case, if I may be pardoned for using such an expression: on the other side it can only be said that no trace of a satellite has ever been found by any subsequent observer with larger telescopes. And with the care bestowed on Venus by Sir W. Herschel and Schröter during so many years, it is difficult to understand that, if a satellite existed, they should not have seen it at some time or other [q].

[p] Scheuten says he saw a satellite accompany Venus across the Sun during the transit of 1761. See *Ast. Jahrbuch*, 1778. Reference may also be made to a letter by Lynn in *The Observatory*, vol. x. p. 73, March 1887.

[q] The question of the existence of a satellite of Venus is very fully discussed,

Lambert combined all the observations in a very tolerable orbit [r], but, as Hind points out [s], notwithstanding its agreement with the observations, there is one fatal objection to it—if it were correct, the mass of Venus would be 10 times greater than what other methods show it to be, namely $\frac{1}{401211}$ that of the Sun. Encke gives $\frac{1}{401839}$, Littrow $\frac{1}{405871}$, Mädler $\frac{1}{401718}$, Le Verrier $\frac{1}{412150}$, and Newcomb $\frac{1}{405000}$. There are several methods of ascertaining this quantity, the most obvious of which is based on the disturbing influence exerted by Venus on the Earth's annual motion.

Venus has ever been regarded as an interesting and popular planet, and it is somewhat remarkable that it is the only one whose praises are sung by the great Greek bard, who thus apostrophises it:—

"Ἕσπερος, ὃς κάλλιστος ἐν οὐρανῷ ἵσταται ἀστήρ [t]."

This refers to it as the Evening Star, but elsewhere in the Iliad [u] we meet with it in its other function of the Ἑωσφόρος, to which the Latin *Lucifer* corresponds. Some have thought, and perhaps not without reason, that it is the object referred to in *Isaiah* xiv. 12.

The earliest recorded observations of Venus date from 686 B.C., and appear on an earthenware tablet now in the British Museum [x].

"Claudius Ptolemy has preserved for us in his *Almagest* many observations of Venus by himself and other astronomers before him, at Alexandria in Egypt. The most ancient of these observations is dated in the 476th year of Nabonassar's era and 13th of

and from a new standpoint, in a paper by M. Bertrand in *L'Astronomie*, vol. i. p. 201, August 1882; but it does not seem worth while to go more fully into the subject here. And see also M. Stroobant's very interesting *Etude sur le satellite énigmatique de Vénus* published at Brussels in 1887. His researches show that in almost all cases stars which can be identified were mistaken for a satellite; in a few instances where the identity is doubtful possibly a minor planet was seen; and in one instance possibly it was Uranus which was seen and mistaken for a satellite of Venus.

r Bode's *Jahrbuch*, 1777.

s *Sol. Syst.*, p. 27.

t Homer, *Iliad*, lib. xxii. v. 318.

u Lib. xxiii. v. 226. Pythagoras (or, according to others, Parmenides) determined the identity of the two "stars."

x *Month. Not.*, vol. xx. p. 319. June 1860.

the reign of Ptolemy Philadelphus, on the night of the 17th of the Egyptian month *Messori*, when Timocharis saw the planet eclipse a star at the extremity of the wing of Virgo. This date answers to 271 B.C., Oct. 12 A.M.[y]" As this was not a telescopic observation, it and all others recorded before telescopes came into use, are open to this uncertainty, that the two objects may merely have been in juxta-positon so as to have appeared as one without actual *super*-position taking place. The recorded occultation of Mercury by Venus on May 17, 1737, was no doubt an occultation in the strict sense of the word.

The interesting discovery of the phases of Venus is due to Galileo[z], who announced the fact to his friend Kepler in the following logogriphe or anagram[a]:—

"Hæc immatura, a me, jam frustra, leguntur.—oy."

"These things not ripe [for disclosure] are read, as yet in vain, by me."

Or, as another interpretation has it—

"These things not ripe; at present [read] in vain [by others] are read by me."

The "me" in the former case being the ordinary reader; in the latter, Galileo.

This, when transposed, becomes—

"Cynthiæ figuras æmulatur Mater Amorum."

"The Mother of the Loves [Venus] imitates the phases of Cynthia [the Moon]."

The letters 'o y' are, it will be observed, redundant, so far that they cannot be made use of in the transposition.

To the mariner, owing to its rapid motion, Venus is a useful auxiliary for taking lunar distances when continuous bad weather may have prevented observations of the Sun.

In computing the places of Venus the tables of Baron De Lindenau, published in 1810, were long in use, but they have now

[y] Hind, *Sol. Syst.*, p. 32.

[z] It was one of the objections urged to Copernicus against his theory of the solar system that if it were true then the inferior planets ought to exhibit phases. He is said to have answered that if ever men obtained the power of seeing them more distinctly, they would be found to do so. Prof. De Morgan believes the anecdote to be apocryphal. (*Month. Not.*, vol. vii. p. 290. June 1847.) But "se non è vero, è ben trovato."

[a] *Opere di Galileo*, vol. ii. p. 42. Ed. Padova, 1744.

been superseded by those of Le Verrier, for amongst other causes of error there existed a long inequality (first suspected by Sir G. B. Airy about 1828, and fully expounded in 1831 [b]) affecting the heliocentric places of the Earth and the planet to a very sensible amount. This inequality goes through all its changes in about 239^y, and when at a maximum displaces Venus by 3″ and the Earth by 2″, as viewed from the Sun.

[b] *Phil. Trans.*, vol. cxviii. p. 23, 1828; vol. cxxii. p. 67, 1832.

CHAPTER VI.

THE EARTH. ⊕

"O let the Earth bless the Lord: yea, let it praise Him, and magnify Him for ever."—*Benedicite.*

Period, &c.—Figure of the Earth.—The Ecliptic.—The Equinoxes.—The Solstices.—Diminution of the obliquity of the ecliptic.—The eccentricity of the Earth's orbit.—Motion of the Line of Apsides.—Familiar proofs and illustrations of the sphericity of the Earth.—Foucault's Pendulum Experiment.—Mädler's tables of the duration of day and night on the Earth.—Opinions of ancient philosophers.—English mediæval synonyms.—The Zodiac.—Mass of the Earth.

THE Earth is a planet which may perhaps be said to be in all essential respects similar to Venus and Mars, its nearest neighbours; but as we are on it, it is needless to point out the impossibility of treating of it in the same way as we treat of the other planets. It revolves round the Sun in $365^d\ 6^h\ 9^m\ 9{\cdot}6^s$, at a mean distance of 92,890,000 miles. The eccentricity of its orbit amounting to 0·01679, this distance may either extend to 94,450,000 miles or diminish to 91,330,000 miles; and these differences involve variations in the light and heat reaching the Earth which will be represented by the figures 966 and 1033, the mean amount being 1000.

The Earth is not a sphere, but an oblate spheroid; that is to say, it is somewhat flattened at the poles and protuberant at the equator; as is the case with probably all of the planets. The following table gives the latest authentic measurements.

	Airy [a].	Bessel [b].
	Miles.	Miles.
Polar Diameter	7899·170	7899·114
Equatorial Diameter...	7925·648	7925·604
Absolute Difference	26·478	26·490
Excess of the Equatorial, expressed as a fraction of its entire length	$\frac{1}{298\cdot330}$	$\frac{1}{299\cdot192}$

The close coincidence between these results affords a good guarantee of the accuracy of both, and is noticeable as an illustration of the precision arrived at in the working out of such problems, the difference between the two values of the equatorial diameter being only 77 yards. If we represent the Earth by a sphere 1 yard in diameter, that diameter will make the polar diameter $\frac{1}{8}$ inch too long.

Further, it has been suspected by General Schubert and Colonel A. R. Clarke that the equatorial section of the Earth is not circular, but elliptical. Colonel Clarke's conclusion is that the equatorial diameter, which pierces the Earth through the meridians 13° 58′ and 193° 58′ E. of Greenwich, is 1 mile longer than the equatorial diameter at right angles to it[c].

A consideration of the method in which such investigations are conducted does not fall within the scope of the present sketch, but in Airy's *Popular Astronomy* the subject of the Figure of the Earth is handled with much clearness[d].

The great circle of the heavens *apparently* described by the Sun every year (owing to our revolution round that body) is called the *Ecliptic*[e], and its plane is usually employed by astronomers as a fixed plane of reference. The plane of the Earth's equator, extended towards the stars, marks out the equator of the heavens, the plane of which is inclined to the ecliptic at an

[a] *Encycl Metrop.*, art. *Fig. of Earth*, vol. v. p. 220.

[b] *Ast. Nach.*, vol. xiv. Nos. 333-5; vol. xix. No. 438.

[c] *Mem. R.A.S.*, vol. xxix. p. 39. 1861.

[d] See p. 242 *et seq.*

[e] "The line of eclipses."

angle which, on Jan. 1, 1880, amounted to 23° 27′ 17·55″; this angle is known as the *Obliquity of the Ecliptic.* It is this inclination which gives rise to the vicissitudes of the seasons during our annual journey round the Sun. The two points where the celestial equator intersects the ecliptic are called the *Equinoxes* [f]; the points midway between these being the *Solstices* [g]. It is from the vernal (or spring) equinox that Right Ascensions are measured along the equator, and Longitudes along the ecliptic. The obliquity of the ecliptic is now slowly decreasing at the rate of about 46″ in 100 years. "It will not always however, be on the decrease; for before it can have altered $1\frac{1}{2}°$ the cause which produces this diminution must act in a contrary direction, and thus tend to increase the obliquity. Consequently the change of obliquity is a phenomenon in which we are concerned only as astronomers, since it can never become sufficiently great to produce any sensible alteration of climate on the Earth's surface. A consideration of this remarkable astronomical fact cannot but remind us of the promise made to man after the Deluge, that 'while the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease.' The perturbation of obliquity, consisting merely of an oscillatory motion of the plane of the ecliptic, which will not permit of its [the inclination] ever becoming very great or very small, is an astronomical discovery in perfect unison with the declaration made to Noah, and explains how effectually the Creator had ordained the means for carrying out His promise, though the way it was to be accomplished remained a hidden secret until the great discoveries of modern science placed it within human comprehension [h]."

It is stated by Pliny that the discovery of the obliquity of the ecliptic is due to Anaximander, a disciple of Thales, who was

[f] From *æquus* equal, and *nox* a night; because when the Sun is at these points, day and night are theoretically equal throughout the world. In 1890 this occurs on March 20 at 4^h, and Sept. 22 at 14^h, G.M.T.

[g] From *sol* the Sun, and *stare* to stand still; because the Sun when it has reached these neutral points has attained its greatest declination N. or S. as the case may be. In 1890 this occurs on June 21 at 0^h, and Dec. 21 at 9^h, G.M.T.

[h] Hind, *Sol. Syst.*, p. 33.

born in 610 B.C. Other authorities ascribe it to Pythagoras or the Egyptians, while Laplace believed that observations for the determination of this angle were made by Tcheou-Kong in China not less than 1100 years before the Christian era[1]. The accord between the various determinations ancient and modern is very remarkable, and indicates the great care bestowed by the astronomers of antiquity on their investigations.

The eccentricity of the Earth's orbit amounts (to be more precise than above) to 0·0167917, and it is subject to a very small diminution, not exceeding 0·000041 in the course of 100 years. Supposing the change to go on continuously, the Earth's orbit must eventually become circular; but we learn from the Theory of Attraction that this progressive diminution is only to proceed for a certain time. Le Verrier has shown that this diminution cannot continue beyond 24,000 years, when the eccentricity will be at its minimum of ·0033: it will then begin to increase again; so that unless some external cause of perturbation arise, these variations may continue throughout all ages, within certain not very wide limits. They are due to the attractive influence of the Planets. The above value of the eccentricity is for 1800·0 A.D.

The line of apsides is subject to an annual direct change of 11·77″, independent of the effects of precession (to be described hereafter); so that, allowing for the latter cause of disturbance, the annual movement of the apsides may be taken at rather more than 1′. One important consequence of this motion of the major axis of the Earth's orbit is the variation in the lengths of the seasons at different periods of time. In the year 3958 B.C., or, singularly enough, near the epoch of the Creation of Adam, the longitude of the Sun's perigee coincided with the autumnal equinox; so that the summer and autumn quarters were of equal length, but shorter than the winter and spring quarters, which were also equal. In the year 1267 A.D. the perigee coincided with the winter solstice; the spring quarter was therefore equal to the summer one, and the autumn quarter to the winter one,

[1] *Conn. des Temps.* 1811, p. 429.

the former being the longest. In the year 6493 A.D. the perigee will have completed half a revolution, and will then coincide with the vernal equinox; summer will then be equal to autumn, and winter to spring; the former seasons, however, being the longest. In the year 11719 A.D. the perigee will have completed three-fourths of a revolution, and will then coincide with the summer solstice; autumn will then be equal to winter, but longer than spring and summer, which will also be equal. And finally in the year 16945 A.D. the cycle will be completed by the coincidence of the solar perigee with the autumnal equinox. This motion of the apsides of the Earth's orbit, in connection with the inclination of its axis to the plane of it, must quite obviously have been the cause of very remarkable vicissitudes of climate in pre-Adamite times[k].

One result of this position of things we may readily grasp at this moment. As a matter of fact, in consequence of our seasons being now of unequal length, the spring and summer quarters jointly extend to 186^d, whilst the autumn and winter quarters comprise only 178^d. The Sun is therefore a longer time in the Northern hemisphere than in the Southern hemisphere: hence the Northern is the warmer of the two hemispheres. Probably it may be taken as one result of this fact, that the North Polar regions of the Earth are easier of access than the South Polar regions. In the Northern hemisphere navigators have reached to 81° of latitude, whereas 71° is the highest attained in the Southern hemisphere.

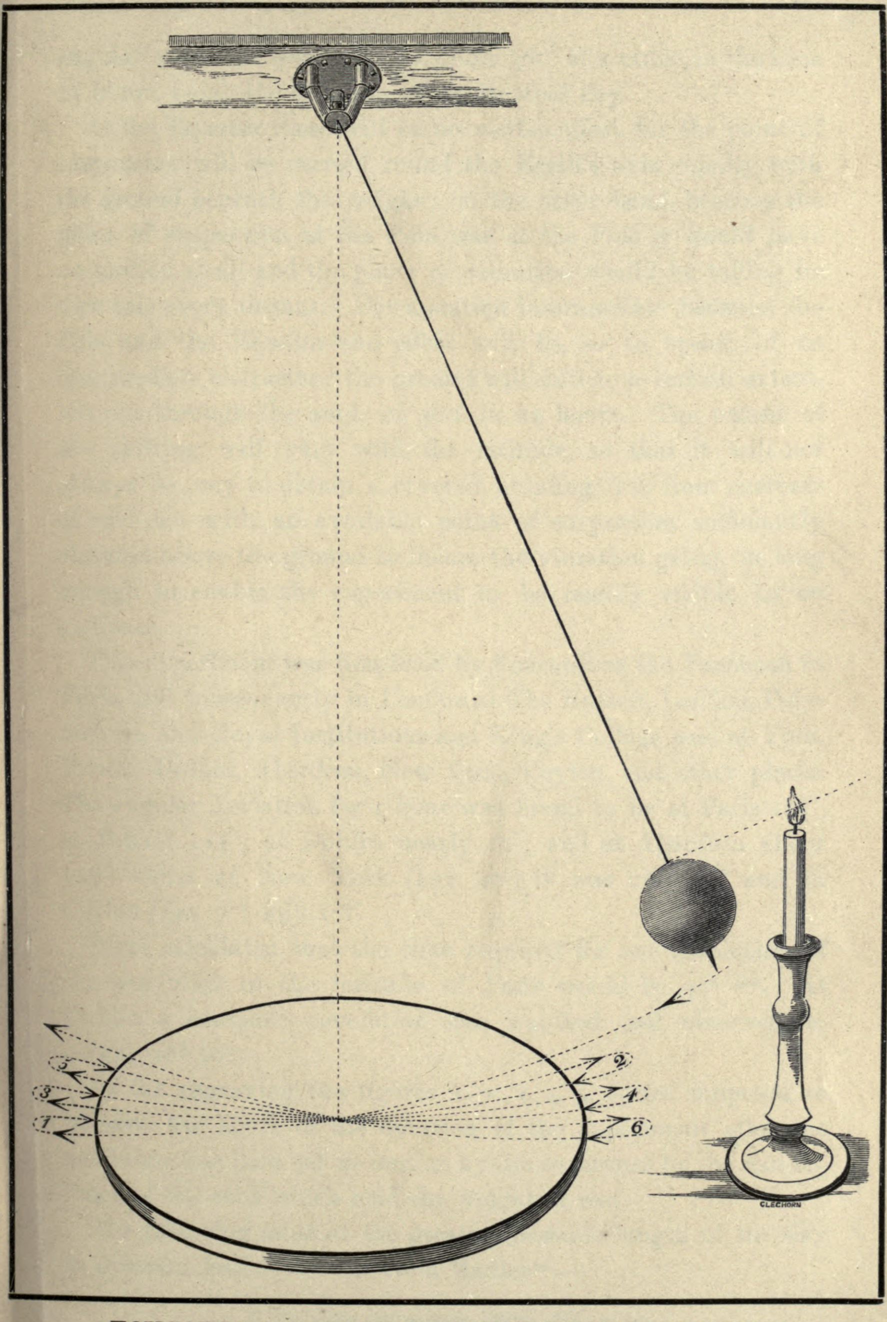
It is not a very easy matter in treating of the Earth to determine where astronomy ends and geography begins; but a brief allusion to the means available for deciding the form of the Earth seems all that it is now necessary to add here. We learn that the Earth is a sphere (or something of the sort) by the appearance presented by a ship in receding from the spectator: first the hull disappears, then the lower parts of the rigging, and finally the top-masts. The shadow cast on the Moon during a

[k] See Papers by Croll, *Phil. Mag.*, 4th Ser., vol. xxxv. p. 363, May 1868; vol. xxxvi. pp. 141 and 362, Aug. and Nov. 1868; Geikie's *Great Ice Age*, &c.

lunar eclipse, and the varying appearances of the constellations as we proceed northwards or southwards, are amongst the other more obvious indications of the Earth's globular form.

Fig. 56, Plate VI, represents an experimental proof of the Earth's rotation on its axis. This particular form of proof excited no small interest in scientific (and unscientific) circles when it was first promulgated by the French *savant* Foucault in the year 1851[1]. If a pendulum, or its equivalent, a heavy weight suspended by a long wire, could be erected at either pole of the Earth, and be set swinging in any direction and a note of the direction taken, it is evident that if the plane of oscillation were observed to be perpetually shifting with regard to the terrestrial point noted at the beginning of the experiment, it would be a proof that either the terrestrial station was shifting with respect to the pendulum or the pendulum was shifting with respect to the station. The latter idea being contrary to reason the former alternative must be adopted. It is evident that both poles of the Earth being inaccessible to us, the experiment cannot be carried out in the theoretically simple fashion suggested above; but in a modified form it can be tried and will yield an intelligible result at a station on the Earth's surface between the Pole and the Equator, provided it be not very near the Equator. The *rationale* of the experiment is simply this, that the weight being made to oscillate in a straight line (and starting it by burning the thread which holds it should secure this) it will swing backwards and forwards in an invariable plane. If the building in which the experiment is tried were at rest, the plane of oscillation would be constantly parallel to a line joining any 2 points in the building if the plane of oscillation had been parallel to that line when the start was made. But if the building moves in consequence of an axial rotation of the Earth, the angle between the plane of oscillation and the line parallel thereto at the start will be continually varying and in the course of some hours will vary through an angular space of many degrees. Could the experiment be tried at the Pole the

[1] See *Proc. Roy. Inst.*, vol. i. p. 70: Arago, *Pop. Ast.*, Eng. ed., vol. ii. p. 27.



FOUCAULT'S PENDULUM EXPERIMENT TO SHOW THE EARTH'S AXIAL ROTATION.

angular variation would be the whole 360° of a circle, in the time 24 hours, being the duration of the sidereal day.

At the Equator there will be no visible effect, for the point of suspension will be carried round the Earth's axis equally with the ground beneath the weight; on the other hand, because the point of suspension at the Pole was at the Pole it would have no motion at all and the plane of vibration would be telling its own tale every instant. For a station intermediate between the Pole and the Equator the effect will be, so to speak, of an intermediate character; the ground will shift to a certain extent, but not through the angle of 360° in 24 hours. The extent of the shifting will vary with the latitude, so that it will not always be easy to obtain a covered building free from currents of air, and with an available point of suspension sufficiently elevated above the ground to insure the vibration going on long enough to enable the experiment to be readily visible to an audience.

This experiment was first tried by Foucault at the Pantheon in Paris, and subsequently in London at The Russell, London, Polytechnic, and Royal Institutions and King's College, and at York, Bristol, Dublin, Aberdeen, New York, Ceylon, and other places. The angular deviation for 1 hour was found to be at Paris $11\frac{1}{2}°$; at Bristol $11\frac{3}{4}°$; at Dublin nearly 12°; and at Aberdeen about $12\frac{3}{4}°$, whilst at New York (Lat. 40°) it was only $9\frac{3}{4}°$ and in Ceylon (Lat. 7°) only 1·8°.

Binet calculated that the time required for one revolution of the pendulum in the latitude of Paris would be $32^h\ 8^m$. At Dublin a complete revolution was watched and observed to occupy $28^h\ 26^m$.

In the engraving the figures 1, 2, 3, 4, 5, 6, are supposed to indicate the hours of the duration of the experiment after the pendulum has been set in motion by the severance by the candle-flame of the cord which held the weight at rest.

The following table of the greatest possible length of the day in different latitudes I cite from Mädler[m]:—

[m] *Populäre Astronomie*, Berlin 1861, p. 30.

°	′	Hours.	°	′	Hours.
0	0	 12	65	48	 22
16	44	 13	66	21	 23
30	48	 14	66	32	 24
41	24	 15	67	23	... ... 1 month.
49	2	 16	69	51	... ... 2 „
54	31	 17	73	40	... ... 3 „
58	27	 18	78	11	... ... 4 „
61	19	 19	84	5	... ... 5 „
63	23	 20	90	0	... ... 6 „
64	50	 21			

The 8646 hours which make up a year, are, according to Mädler, thus distributed:—

At the Equator.		At the Poles.	
4348	hours Day,	4389	hours Day,
852	„ Twilight,	2370	„ Twilight,
3449	„ Night.	1887	„ Night.

Among the ancients, Aristarchus of Samos, and Philolaüs, maintained that not only did our globe rotate on its own axis, but that it revolved round the Sun in 12 months[n]. Nicetas of Syracuse is also mentioned as a supporter of this doctrine[o]. The Egyptians taught the revolution of Mercury around the Sun[p]; and Apollonius Pergæus assigned a similar motion to Mars, Jupiter, and Saturn—but I am digressing.

Hesiod states that the Earth is situated exactly half-way between Heaven and Tartarus:—

> "From the high heaven a brazen anvil cast,
> Nine days and nights in rapid whirls would last,
> And reach the Earth the tenth; whence strongly hurl'd,
> *The same the passage to th' infernal world.*"
>
> *Theogonia*, ver. 721.

Our ancestors 300 or 400 years ago termed the ecliptic the "thwart circle"; the meridian, the "noonsteede circle"; the equinoxial, "the girdle of the sky"; the Zodiac, "the Bestiary,"

[n] Archimedes, *In Arenario*; Plutarch, *De Placit. Philos.*, lib. ii. cap. 24; Diog. Laert. *In Philolao.*

[o] Cicero, *Acad. Quæst.*, lib. ii. cap. 39.

[p] Macrobius, *Comment. in Somn. Scip.*, lib. i. cap. 19, and others.

and "our Lady's waye." The origin of the division of the zodiac into constellations is lost in obscurity. Though often attributed to the Greeks, it now seems certain that the custom is of much earlier date; and is possibly due to the Egyptians or even to the ancient Hindûs or the Chinese, in whose behalf, however, a claim to prior knowledge is always put in, whenever we Europeans fancy that we have made a discovery.

The following are recent values of the mass of the Earth compared with that of the Sun:—Encke $\frac{1}{389551}$, Littrow $\frac{1}{355000}$, Mädler $\frac{1}{355499}$, and Le Verrier $\frac{1}{354030}$. Le Verrier, however, once seemed to consider that these values were all too small, but that in our state of uncertainty as to the Sun's parallax it was not possible to assign with confidence a definitive value[q]. Newcomb taking the Earth and the Moon together gives for their combined mass the fraction $\frac{1}{327000}$, or for the Earth alone $\frac{1}{332260}$.

[q] See *Month. Not.*, vol. xxxii. pp. 302 and 323. 1872.

CHAPTER VII.

THE MOON. ☾

Period, &c.—Its Phases.—Its motions and their complexity.—Libration.—Evection.—Variation —Parallactic Inequality.—Annual Equation.—Secular acceleration.—Diversified character of the Moon's surface.—Lunar mountains.—Seas.—Craters.—Volcanic character of the Moon.—Bergeron's experiment.—The lunar mountain, Aristarchus.—Teneriffe.—Lunar atmosphere.—Researches of Schröter, &c.—Hansen's curious speculation.—The Earth-shine.—The Harvest Moon.—Astronomy to an observer on the Moon.—Luminosity and calorific rays.—Historical notices as to the progress of Lunar Chartography.—Lunar Tables.—Meteorological Influences.

THE Moon, as the Earth's satellite, is to us the most important of the "secondary planets," and will therefore receive a somewhat detailed notice.

The Moon revolves round the Earth in $27^d\ 7^h\ 43^m\ 11{\cdot}461^s$, at a mean distance of 237,300 miles. The eccentricity of its orbit amounting to 0·0662, the Moon may recede from the Earth to a distance of 253,000 miles, or approach it to within 221,600 miles. Its apparent diameter[a] varies between 29′ 21″ and 33′ 31″. The diameter at mean distance is 31′ 5″. It will fix this in the memory to note that the apparent diameter is the same as the Sun's, and equals ½°. The real diameter, according to Mädler, is 2159·6 miles; according to Wichmann 2162 miles. Recent researches shew that these values are too great; and that a correction of about 2″ (Airy) or 2·15″ (De La Rue) must be applied to the measured visual diameter of the Moon, to allow

[a] These figures must be regarded as geometrically rather than practically true, for under varying circumstances of altitude above the horizon the diameter of the Moon will be found to vary considerably. And the diameter at mean distance is not the arithmetical mean of the extremes of apparent diameter.

for the exaggeration of its dimensions by irradiation. This reduction amounts to about 2 miles. The most delicate measurements indicate no compression.

The Moon has phases like the inferior planets; and of the various influences ascribed to it, that which results in the tides of the ocean is the most important, and will hereafter be treated at some length.

The motions of the Moon are of a very complex character: they have largely occupied the attention of astronomers during all ages, and it is only within a recent period that they can be said to have been mastered.

Speaking roughly, we may say that the same hemisphere of the Moon is always turned towards us; but although this is, in the main, correct, yet there are certain small variations at the edge which it is necessary to notice. The Moon's axis, although nearly, is not exactly perpendicular to the plane of its orbit, deviating therefrom by an angle of 1° 32′ 9″ (Wichmann); owing to this fact, and to the inclination of the plane of the lunar orbit to that of the ecliptic, the poles of the Moon lean alternately to and from the Earth. When the North pole leans towards the Earth we see somewhat more of the region surrounding it, and somewhat less when it leans the contrary way; this is known as *libration in latitude*[b]. The extent of the displacement in this direction is 6° 47′. In order that the same hemisphere should be continually turned towards us, it would be necessary not only that the time of the Moon's rotation on its axis should be precisely equal to the time of the revolution in its orbit, but that the angular velocity in its orbit should, in every part of its course, exactly equal its angular velocity on its axis. This, however, is not the case, for the angular velocity in its orbit is subject to a slight variation, and in consequence of this a little more of its Eastern or Western edge is seen at one time than another; this phenomenon is known as the *libration in longitude*, and was discovered by Hevelius, who described it in 1647[c]. The extent of the displacement in longitude is 7° 53′.

[b] *Librans*, balancing.

[c] In his *Selenographia*.

The maximum total libration (as viewed from the Earth's centre) amounts to 10° 24′. On account of the diurnal rotation of the Earth, we view the Moon under somewhat different circumstances at its rising and at its setting, according to the latitude of the Earth in which we are placed. By thus viewing it in different positions, we see it under different aspects; this gives rise to another phenomenon, the *diurnal libration*, but the maximum value of this is only 1° 1′ 24″.

This periodical variation in the visible portion of the Moon's disc seems to have been first remarked by Galileo—a discovery very creditable to him when we consider the materials with which he worked. According to Arago, the various librations enable us to see altogether $\frac{57}{100}$ of the Moon's surface, the portion always invisible amounting only to $\frac{43}{100}$ of the same.

The following account of the chief perturbations in the motion of the Moon is, in the main, abridged from that invaluable repertory of astronomical facts, Hind's *Solar System.*

1. The *Evection* depends on the angular distance of the Moon from the Sun, and on the mean anomaly of the former. It diminishes the equation of the centre in the syzygies and increases it in the quadratures, increasing or diminishing the Moon's mean longitude by 1° 20′ 29·9″. Period, about 31^d 19^h 30^m. Discovered by Ptolemy, but previously suspected by Hipparchus.

2. The *Variation* depends solely on the angular distance of the Moon from the Sun. Its effect is greatest at the octants, and disappears in the syzygies and quadratures, the longitude of the Moon being altered thereby 35′ 41·6″ when at a maximum. Period, half a synodical revolution, or about 14^d 18^h. Its discovery is usually ascribed to Tycho Brahe, but Sedillot and others claim it for Abùl Wefa, who lived in the 9th century. It was the first lunar inequality explained by Sir I. Newton on the Theory of Gravitation.

3. The *Parallactic Inequality* arises from the sensible difference in the disturbing influence exerted by the Sun on the Moon, according as the latter is in that part of its orbit nearest to,

or most removed from, the Sun. At its maximum it alters the Moon's longitude by about 2′. Period, one synodical revolution, or $29^d\ 12^h\ 44^m$.

4. The *Annual Equation* is that inequality in the Moon's motion, which results from the variation in the velocity of the Earth, caused by the eccentricity of its orbit. At its maximum the Moon's longitude is altered by 11′ 11·97″. Period, one anomalistic solar year, or $365^d\ 6^h\ 13^m\ 49{\cdot}3^s$.

5. The *Secular Acceleration* of the Moon's mean motion had been supposed to be caused wholly by the diminution in the eccentricity of the Earth's orbit which has been going on for many centuries, as has already been pointed out; but in 1853 it was shewn by Professor Adams that the amount of this acceleration is just double that which such diminution *per se* would account for. At present the mean motion of the Moon is being increased at the rate of about 12″ every 100 years. This inequality was detected by Halley in 1693 from a comparison of the periodic time of the Moon, deduced from Chaldæan observations of eclipses, made at Babylon in the years 720 and 719 B.C., and Arabian observations made in the 8th and 9th centuries A.D. Laplace first reasoned out and explained the theory of the inequality, and up to the date of Adams's researches his calculations were supposed to be complete. It was, however, shewn by our great geometer that Laplace had neglected certain quantities in his calculations, and so estimated the accelerating effect of the increase of the minor axis of the Earth's orbit at double its true amount. It has been suggested by Delaunay and others that half of this seeming acceleration has its origin in the real increase in length of our terrestrial day, which has actually lengthened and continues to lengthen by a small fraction of a second annually; and this slower rotation of the Earth (for that is what it amounts to) is conceived to have its origin in the friction of the tides, which act as a break on the Earth rotating beneath them.

Hansen elucidated, a few years ago, two other inequalities in the Moon's motion, due, the one directly and the other indirectly to the influence of Venus[d]; and it was hoped that when these were taken into account it would have been found possible to say that the position of the Moon deduced from theory is almost precisely the same as that obtained by direct observation, and therefore that our knowledge of the Moon's motion is almost perfect; but further research by Sir G. B. Airy has cast a doubt on the matter.

Some matters connected with the Moon's orbit which are of importance in relation to eclipses will be referred to when we come to deal with eclipses (Book II., *post*); but it is desirable to note here the fact that the line of nodes of the lunar orbit revolves round the ecliptic in a retrograde direction in $18^y\ 218^d\ 21^h\ 22^m\ 46^s$. "This retrogression of the nodes is caused by the action of the Sun which modifies the central gravity of the Moon towards the Earth. It is not, however, an equable motion throughout the whole of the Moon's revolution; the node, generally speaking, is stationary when she is in quadrature, or in the ecliptic; in all other parts of the orbit it has a retrograde motion, which is greater the nearer the Moon is to the syzygies, or the greater the distance from the ecliptic. The preponderating effect at the end of each synodic period is, however, retrocessive, and gives rise to the revolution of the line of nodes in between 18 and 19 years[e]."

This motion must not be confused with the motion of the line of apsides of the lunar orbit. "The line of apsides or major axis of the lunar orbit has, from a similar cause, a direct motion on the ecliptic, and accomplishes a whole revolution in $8^y\ 310^d\ 13^h\ 48^m\ 53^s$, so that in $4^y\ 155^d$ the perigee arrives where the apogee was before. This motion of the line of apsides, like the movement of the nodes, is not regular and equable throughout the whole of a lunar month; for when the Moon is in syzygies the line of apsides advances in the order of signs, but is

[d] The statement in the text is not quite correct, so far that in the case of one of these inequalities (the 239-year one) what Hansen did was to trace the operation on the Moon of that influence of Venus which Airy connected only with the Earth. The second of these Hansen inequalities runs its course in 273 years. See on the whole subject a paper by Airy in *Month. Not.*, vol. xxxiv. p. 1. Nov. 1873.

[e] Hind, *Sol. Syst.*, p. 42.

retrograde in quadratures. But the preponderating effect in several revolutions tends to advance the apsides, and hence arises their revolution in between 8 and 9 years."

Fig. 57.

VIEW OF A PORTION OF THE MOON'S SURFACE ON THE S.E. OF TYCHO. (*Nasmyth.*)

When viewed by the naked eye the Moon presents a mottled appearance; this arises from our satellite being unequally reflective, a fact which the telescope teaches us to be due to numerous mountains and valleys on its surface, as was discovered by Galileo. The proof of the existence of these is found in the shadows cast by the high peaks on the surrounding plains, when the Sun shines obliquely; these shadows disappear, however, at the full phase, as the Sun then shines perpendicularly on the Moon's surface. Between the times of New and Full Moon the boundary line of the illuminated portion (often called the "Terminator") has a rough jagged appearance: this is caused by the Sun's light falling first on the summits of the peaks, the surrounding valleys and declivities being still in shade; thus a disconnected form is given to the whole edge, and so arises the jagged aspect above referred to.

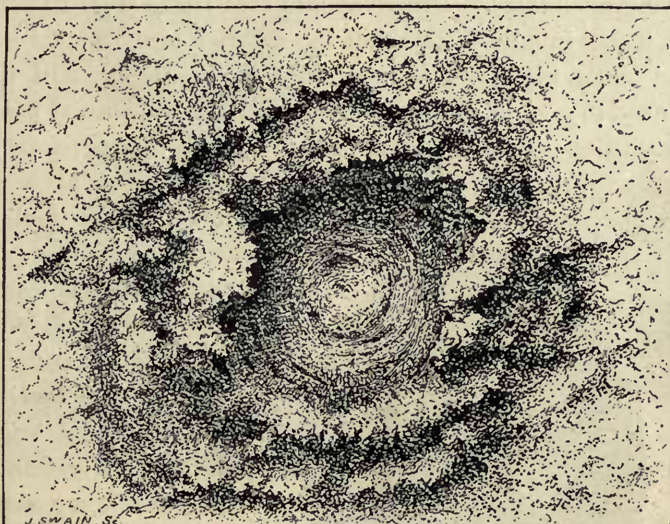
Most of the lunar mountains have received names, chiefly those of men eminent in science, both ancient and modern. Riccioli proposed this nomenclature as preferable to that of Hevelius, who adopted terrestrial geographical names. Beer and Mädler, to whom we owe so much of our knowledge of the Moon, measured the heights of 1095 lunar elevations, several of which exceed 20,000^{ft}. But the absence of water on the Moon makes the choice of a *datum* line difficult.

Grey plains, or *seas*, analogous probably to our "steppes" and prairies, form another noticeable feature in the topography of the Moon. They were called "seas" from their supposed nature, but though the opinion is overthrown the appellation is retained, and specific names have been applied to several of them.

The *crater mountains* are by far the most curious objects shewn by the telescope. These are apparently of volcanic origin, and usually consist of a basin with a conical elevation rising from the centre. Their outline is generally circular or nearly so, but oblique view will often give those in the neighbourhood of the limb an apparently elliptical contour. Their immediate formation is probably due to the escape of gases from the interior of the Moon when that body was in a semi-fluid state, as it is conceived once to have been. The effect of the passage of air through a semi-fluid substance may be seen in the case of lime slaked by builders for fine plastering, when the air-bubbles, having forced their way upwards to the surface and burst, leave apertures rising in cones forming a good imitation of many lunar craters.

Some further experimental proof is to be had of the soundness of this view. Bergeron, having noticed the manner in which gases or vapours, when they pass through a pasty mass, leave a series of funnel-shaped holes behind them, and struck with the analogy which these holes present to the craters of the Moon, tried to reproduce the phenomenon on a larger scale, and for that purpose caused a current of hot air to pass through

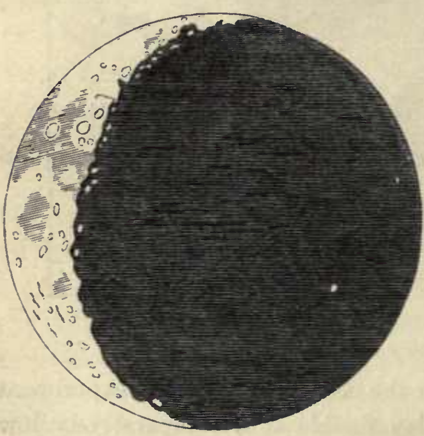
Fig. 58.



IMITATION OF THE STRUCTURE OF THE MOON'S SURFACE.
(*Bergeron's experiment.*)

a mass of molten metal. For the convenience of the experiment the metal chosen was an alloy fusible at a comparatively low temperature, Wood's alloy, which melts at about 158° F., being the first employed. A current of hot air was forced through the alloy, which was melted in a hot-water bath. Then, as the metal was allowed to cool slowly, the supply of air being kept up, a bubbling was created, which drove away the particles which were beginning to solidify from over a considerable area and a large ring was formed. The air still being blown through, the edges of the ring rose little by little, and a perfect model of a crater was produced; and as the process of cooling went on a cone was formed, and the crater at the same time grew deeper, its inner slopes shewing a much greater inclination than the outer. When the process of forcing the air through the alloy was interrupted, a second inner ring was formed, reminding the experimenter of the appearance presented by Copernicus, Archimedes, and other lunar craters. M. Bergeron considers that his experiments throw much light on the past history of the Moon. Instead of air, various vapours may have given rise to the craters and ring-mountains. These vapours rose freely from the Moon when it was in a fluid state, but the exterior of the planet being cooled more rapidly than the interior, the latter, still fluid, continued to give off vapours when the surface had already become a pasty mass. These vapours passed through this envelope and found a vent at certain points only, doubtless where the tendency to solidification was least[f].

Fig. 59.



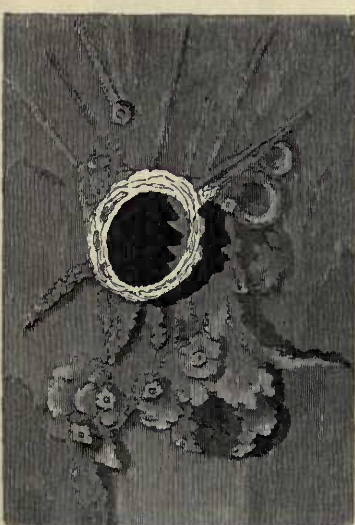
THE LUNAR MOUNTAIN, ARISTARCHUS, ILLUMINATED.

Cassini, Sir W. Herschel, Kater, Smyth, and other observers have fancied a mountain named Aristarchus to be a volcano in action. It is now generally understood that the faint illumination discerned on the summit is merely due to the "Earthshine"; but, in the words of Sir J. Herschel, "decisive marks of volcanic stratification, arising from successive deposits of ejected matter, and evident indications of lava currents streaming outwards in all directions, may be clearly traced with powerful telescopes. In

[f] *Comptes Rendus*, vol. xcv. p. 324, 1882.

Lord Rosse's magnificent reflector the flat bottom of the crater called Albategnius is seen to be strewed with blocks, not visible in inferior telescopes, while the exterior ridge of another (Aristillus) is all hatched over with deep gullies radiating towards its centre[g]." The accompanying engraving represents Aristarchus as seen by Smyth on Dec. 22, 1835, with its peak illuminated. Figs. 60 and 61 shew under opposite phases

Fig. 60.



WAXING.

Fig. 61.

WANING.

THE LUNAR MOUNTAIN, ARISTARCHUS.

of illumination the streaky radiations surrounding Aristarchus which may or may not betoken streams of lava which have flowed away in various directions after being erupted from the crater. The external height of Aristarchus has been calculated to be 2500 ft, and its internal depth 7000 ft. Of Copernicus it may be remarked that it is near the Terminator and is seen under the most favourable conditions of illumination a day or two after the 1st Quarter.

[g] *Outlines of Ast.*, p. 283.

The Volcanic origin of the lunar craters cannot be more plainly demonstrated than by comparing an engraving such as Fig. 62, which represents a *known* volcano—Teneriffe—with any good engraving of a lunar crater, *e.g.* Copernicus, Fig. 65. The similarity is too striking to admit of there being any doubts as to the identity of the physical causes which have originated each surface.

Fig. 62.

THE PEAK OF TENERIFFE. (*C. P. Smyth.*)

A systematic topographical description of the Moon would be entirely beyond the compass of this work, and there is the less occasion for it as that by the Rev. T. W. Webb[h] is a very exhaustive one. The works of Hind[i] and Arago[k] also contain briefer accounts.

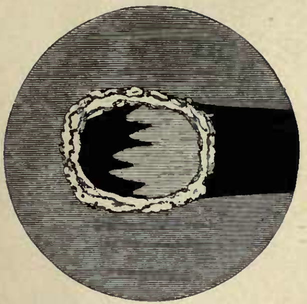
The question as to whether or not the Moon has an atmosphere[l]

[h] *Celest. Objects for common Telescopes.*

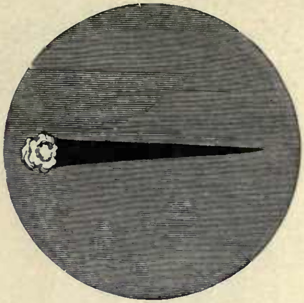
[i] *Sol. Syst.*, p. 48 *et seq.*

[k] *Pop. Ast.*, vol. ii. p. 258 *et seq.*, Eng. ed.

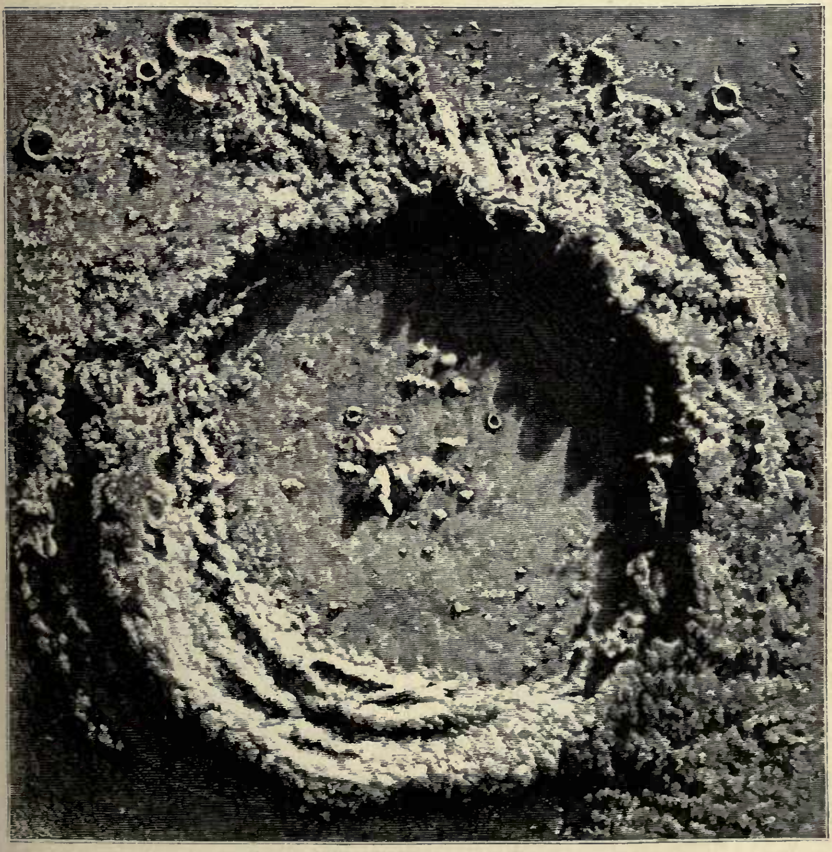
[l] See an important memoir by Bessel in *Ast. Nach.*, vol. xi. p. 411. July 16, 1834. And the reader will do well to consult a paper by Prof. Challis in *Month. Not.*, vol. xxiii. p. 231. June 1863. And Neison has written on this subject. (*The Moon*, p. 19.)



ARCHIMEDES. (*Schröter.*)

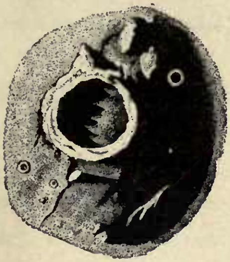


PICO. (*Schröter.*)

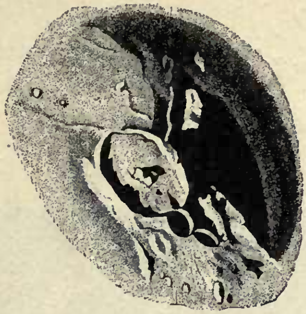


COPERNICUS. (*Nasmyth.*)

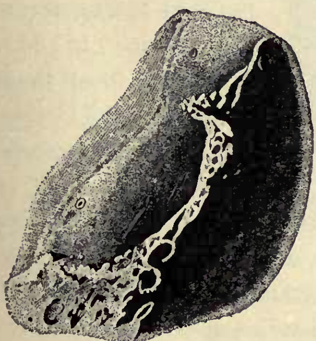
LUNAR MOUNTAINS.



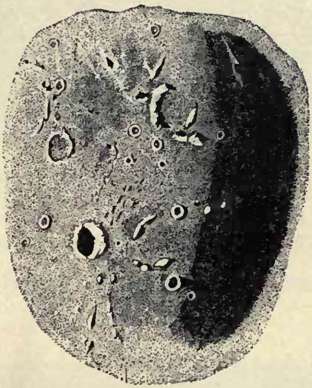
ARCHIMEDES. April 3, 1884.
$8^h\ 45^m$ to $9^h\ 45^m$ p.m.



GASSENDI. April 6, 1884.
$9^h\ 0^m$ to $10^h\ 45^m$ p.m.



SINUS IRIDUM. July 3, 1884.
$9^h\ 45^m$ to $11^h\ 15^m$ p.m.



KEPLER AND ENCKE. Aug. 8, 1884.
$8^h\ 30^m$ to $10^h\ 15^m$ p.m.

FRASCATORIUS. Aug. 10, 1884.
$14^h\ 0^m$ to $15^h\ 45^m$.

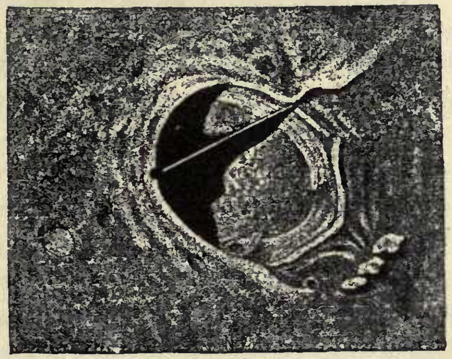
PLATO. Nov. 10, 1884.
$18^h\ 15^m$—$18^h\ 45^m$.

LUNAR MOUNTAINS.

(*Dr L. Weinek.*)

must be answered in the negative, though some affirmative testimony is forthcoming. Schröter considered there is one, but he estimated the height at only 5376 ft, and Laplace thought it to be more attenuated than the best attainable vacuum of an air-pump. Schröter arrived at his conclusion by following up a remark of Auzout's [m], that if the Moon had an atmosphere the phenomenon of twilight would in consequence present itself. He was at length able, he thought, to determine that when the Moon exhibited a very slender crescent, a faint crepuscular light, extending from each of the cusps along the circumference of the unenlightened portion of the disc to a distance of 1′ 20″, could be perceived; its greatest breadth being 2″. He thence inferred the height of the atmosphere to be only 0·94″, corresponding to the 5376 ft given above [n]. The Moon would describe this arc in less than 2 seconds of time, and this circumstance was adduced by Schröter as an explanation of the difficulty attending its direct detection during eclipses and occultations. Sir J. Herschel considered that we are entitled to conclude

Fig. 72.



THE LUNAR MOUNTAIN EUDOXUS, SHOWING WALL ACROSS THE CRATER. (*Trouvelot.*)

Fig. 73.

THE GULF OF IRIS SEEN WHEN THE MOON IS 10 DAYS OLD.

m *Mém. Acad. des Sciences*, vol. vii. p. 106.

n *Phil. Trans.*, vol. lxxxii. p. 354. 1792.

the non-existence of any atmosphere at the Moon's surface dense enough to cause a refraction of 1″, *i.e.* having $\frac{1}{1980}$ the density of the Earth's atmosphere [o]. Both Beer and Mädler thought that the Moon has an atmosphere, but that it is of insignificant extent, owing to the smallness of our satellite's mass; and they also say, "It is possible that this weak envelope may sometimes, through local causes, dim or condense itself,"—an idea which, if proved, would help to clear up some of the conflicting details of occultation phenomena. The suddenness with which occultations of stars by the Moon take place is, however, commonly regarded as one of the best proofs that a lunar atmosphere does *not* exist. And the spectroscope supplies negative evidence of like import.

"Professor Hansen has recently started a curious theory, from which he concludes that the hemisphere of the Moon which is turned away from the Earth may possess an atmosphere. Having discovered certain irregularities in the Moon's motion, which he was unable to reconcile with theory, he was led to suspect that they might arise from the centre of gravity of the Moon not coinciding with her centre of figure. Pursuing this idea, he found upon actual investigation that the irregularities would be almost wholly accounted for by supposing the centre of gravity to be situated at a distance of 33½ miles [p] *beyond* the centre of figure. Assuming this hypothesis to be well founded, Professor Hansen remarks that the hemisphere of the Moon which is turned towards the Earth is in the condition of a high mountain, and that consequently we need not be surprised that [little or] no trace of an atmosphere exists; but that on the opposite hemisphere, the surface of which is situated *beneath* the mean level, we have no reason to suppose that there may not exist an atmosphere, and consequently both animal and vegetable life [q]." Professor Newcomb however has disputed these conclusions of Hansen, which it is obvious must be very difficult of either proof or disproof.

For a few days, both before and after New Moon, an attentive

[o] *Outlines of Ast.*, p. 284. This fraction is probably erroneous. Neison makes it $\frac{1}{2000}$.

[p] "1740" in the English original, but erroneously so, though how the mistake has crept in is not clear.

[q] Note by translator, Arago's *Pop. Ast.*, vol. ii. p. 276, Eng. ed.

observer may often detect the outline of the unilluminated portion without much difficulty. This lustre is the light reflected on the Moon by the Earth—"Earth-shine" in fact; the French call it *la lumière cendrée*, following the Latin *lumen incinerosum*, or the "ashy light." In England it is popularly known as "the Old Moon in the New Moon's arms." This light is stronger during the waning of the Moon than at any other time; as was noticed by Galileo, whose opinion was confirmed by Hevelius and other more modern astronomers. Hevelius remarked, moreover, that in the waning Moon the illumination is less intense than when the phases are increasing—a fact which would seem to indicate, as Arago has pointed out [r], that the Western part of the lunar disc is on the whole better adapted for reflecting the solar rays than the Eastern part; assuming this to be true, an obvious explanation is furnished for the fact that the Earth-shine is more luminous before the New Moon than after it. Janssen, in 1881, succeeded in photographing the "Earth-shine" on the Moon when the latter was 3 days old. In the photographs the "continents" were plainly distinguishable from the "seas [s]."

The *Harvest Moon* is the name given to that full Moon which falls nearest to the autumnal equinox; as our satellite then rises almost at the same time on several successive evenings, and at a point of the horizon almost precisely opposite to the Sun (so that the duration of its visibility is about the maximum possible), it is of much assistance to the farmer at that important period of the year. In the words of Ferguson, "The farmers gratefully ascribe the early rising of the full Moon at that time of the year to the goodness of God, not doubting that He had ordered it so on purpose to give them an immediate supply of moonlight after sunset, for their greater conveniency in reaping the fruits of the Earth [t]." Although this near coincidence in several successive risings of the Moon takes place in every lunation when our satellite is in the signs Pisces and Aries, yet the phenomenon is

[r] Arago, *Pop. Ast.*, vol. ii. p. 300, Eng. ed.
[s] *Nature*, vol. xxiii. p. 518. March 31, 1881.
[t] *Astronomy*, p. 136. Ed. of 1757.

only prominently noticeable when it is "full" in these signs, which only occurs at or near the autumnal equinox, and when the Sun is in Virgo or Libra. The rationale of the harvest Moon is this:—Suppose the Moon to be full on the day of the autumnal equinox, the Sun is then entering Libra, and the Moon, Aries; the former setting exactly in the West, the latter rising exactly in the East: the Southern half of the ecliptic is then entirely above the horizon, and the Northern half entirely below, and the ecliptic itself makes the least possible angle with the horizon. The Moon in then advancing 13°, or one day's portion, in its orbit (which is but slightly inclined to the ecliptic) will become less depressed below the horizon, and will therefore have a less hour-angle to traverse by the diurnal motion after sunset in order that it may come into view the next night than at any other time[u]. That harvest Moon is (*astronomically*) most favourable which happens about Sept. 23, with the Moon in the ascending node of her orbit, which then coincides with the vernal equinox. Under such circumstances the Moon may rise for 2 or 3 nights, later, night by night, by no more than about 10^m.

As a rule however, the variation between the times of two successive risings will seldom be less than about 17^m; whilst the greatest possible variation is about $1^h\ 16^m$; this takes place when the Moon is in Libra, and at the same time at or near its descending node.

The Moon next after the Harvest Moon is (or used to be) called the *Hunter's Moon.*

It is in winter (just when it is most wanted, indeed) that there is most moonlight for dwellers in the Earth's Northern hemisphere. That is to say, the Moon is at its full at the same time that it is at its highest possible Northern altitude, and therefore longest above the horizon; in other words, the Earth's Northern hemisphere experiences the maximum possible amount of exposure to Moonlight. All this is the necessary result of the fact that Full Moon happens when our satellite is 180° away

[u] In Lockyer's *Elementary Lessons in Astronomy* (p. 172) there is a good diagram and description dealing with this matter.

from the Sun, *i.e.* exactly opposite to it. At midwinter, the Sun being at its maximum depression, obviously the Moon is at its maximum elevation, with the result above stated. This recital will be complete by adding that the nights of short Moon in winter are also the nights before and after New Moon, when there is the smallest possible amount of Moonlight to lose. In summer, of course, in the Earth's Northern hemisphere the reverse of all this is the condition of things: the Moon's elevation above the horizon is the minimum possible, and the Earth's exposure to the Moon's rays is consequently also the minimum possible.

As seen from the Sun, with the Earth in perihelion and the Moon in apogee, the Moon never departs more than 10′ 42″ from the Earth at its greatest Elongation. Since the axis of the Moon is very nearly perpendicular to the plane of her orbit, our satellite has of course scarcely any change of seasons. At its equator the mean solar day has a constant length of $354^h\ 22^m$, or $14^d\ 18^h\ 22^m$ of our mean solar time; in other words, it is equal to half the period of the Moon's *synodical* revolution round the Earth. As is the case on the Earth, the length of the longest day on the one hand and of the shortest on the other increases and diminishes according as the assumed place of observation approaches the lunar poles: so that at the selenographic latitude of 45° these times become $14^d\ 21^h\ 19^m$ and $14^d\ 15^h\ 26^m$; and at the latitude of 88°, $18^d\ 17^h\ 28^m$ and $10^d\ 19^h\ 16^m$ respectively.

By an observer placed on the Moon some astronomical phenomena would be witnessed under circumstances widely different from those under which we see them. The apparent diameter of the Earth would be about 2°, and its apparent superficial extent 13 times greater than the apparent superficial extent of the Moon as seen from the Earth. More than this: the Earth is almost a fixed object in the lunar heavens, only altering its place by the amount of the libration, or traversing backwards and forwards a space having an extent of 15° 30′ in longitude and 13° 18′ in latitude. The Earth exhibits to the Moon exactly the same kind of phases which the latter does to us, but in *a reverse order.* For when the Moon is Full, the Earth is invisible to the Moon; and when the Moon is New, the Earth is Full to the Moon. These remarks apply only to those parts of the lunar surface which are turned towards our globe; for a spectator on the opposite side would never see the Earth at all, and spectators located on the apparent borders of the lunar disc would only now and then obtain a glimpse of it in their horizon, for which they would be indebted to the librations in longitude and latitude already noticed.

If the whole sky were covered with Full Moons they would scarcely make daylight, for Bouger's experiments[x] give the brilliancy of the full Moon as only $\frac{1}{300000}$ that of the Sun. Wollaston's value is $\frac{1}{801072}$,[y] Zöllner's $\frac{1}{618000}$, and G. P. Bond's $\frac{1}{470980}$.[z]

The Moon's surface is supposed to be much heated, *possibly*, according to Sir J. Herschel, to a degree much exceeding that of boiling water[a]; yet we are not in a general way conscious of there being any heat at all available for warming the Earth. This need not however excite surprise, for it is probably very small in amount, and what there is of it is doubtless quickly absorbed in the upper strata of our atmosphere. Melloni, in 1846, thought that he detected a sensible elevation of temperature by concentrating the rays of the Moon in a lens 3^{ft} in diameter. C. P. Smyth, in 1856, also thought that he obtained evidence on Teneriffe[b] of the Moon's rays possessing calorific power, but his instrumental appliances were not very perfect. Professor Tyndall has stated that his experiments in 1861 seem to show that the Moon imparts to us, or at least to the Professor's thermometric apparatus, "*rays of cold*." More recently, however, the Earl of Rosse, M. Marié-Davy, and Prof. Langley have conducted experiments which seem to give conclusively affirmative results, and on the whole the balance of evidence leans to this view of the question[c].

[x] Cited by La Place, *Système du Monde*, Bk. I., cap. 4.

[y] *Phil. Trans.*, vol. cxix. p. 27. 1829.

[z] *Month. Not.*, vol. xxi. p. 200. May 1861.

[a] *Outlines of Ast.*, p. 285.

[b] *An Astronomer's Experiment, &c.*, p. 213.

[c] See a summary of all the experiments hitherto made given by Carpenter in *Pop. Sc. Rev.*, vol. ix. p. 1. January 1870. Lord Rosse's experiments will be found described in *Phil. Trans.*, vol. clxiii. p. 587. 1873. See also *Month. Not.*, vol. xxxiv. p. 197. Feb. 1874.

Prof. Langley's summary of his own observations and deductions is as follows:—"While we have found abundant evidence of heat from the Moon, every method we have tried, or that has been tried by others, for determining the character of this heat appears to us inconclusive; and, without questioning that the Moon radiates heat earthward from its soil, we have not yet found any experimental means of discriminating with such certainty between this and reflected heat that it is not open to misinterpretation[d]."

The first astronomer who paid much attention to the delineation of the Moon's surface was Hevelius, who in his well-known *Selenographia*, published in 1647, gave a detailed description of it, accompanied by one general and some 40 special charts; which, taking into consideration the inferior optical means at his disposal, were very creditable to the industry of the illustrious observer of Dantzig. Four years later Riccioli brought out a map of the Moon, having proper names assigned to many of the principal localities: and this nomenclature, improved and enlarged, is still in general use. J. D. Cassini and T. Mayer of Göttingen published charts in the years 1680 and 1749 respectively, the latter of which was the only one used by observers for many years subsequent to the opening of the present century. In 1791 Schröter published a large work entitled *Selenotopographische Fragmente*, in which are given diagrams of many of the principal spots[e]. Schröter was an industrious observer, but his descriptions are not always satisfactory.

In 1824, W. G. Lohrmann of Dresden published the first 4 of a series of 25 excellent lunar charts, but was prevented by failing sight from continuing the work. It was, however, taken up by others and completed in 1878[f]. Beer and Mädler's elaborate *Mappa Selenographica* was published in 1837, and is undoubtedly the best of the kind yet published; but the most generally useful and also most generally accessible map for the class of

[d] *Mem. Nat. Acad. Sciences*, vol. iii. p. 42. 1885.

[e] The two engravings on Plate VII are copied from this work; Archimedes from Plate XVI, and Pico from Plate XXII.

[f] *Month. Not.*, vol. xxxix. p. 267. Feb. 1879. Published by J. A. Barth, Leipzig; price, with book, 50 marks.

readers whom I address is the Rev. T. W. Webb's, reduced from Beer and Mädler's. Undoubtedly, however, the most minutely accurate and elaborate lunar map yet made is the one of $7{\cdot}67^{ft}$ in diameter, by Schmidt of Athens, published at the expense of the German Government in 1878. Maps by Russell and by Blunt are in circulation, but they are not of much value as regards details.

The British Association for the Advancement of Science, through a sub-committee, began in 1866 the preparation of an entirely new map of the Moon, but this was eventually abandoned by the Association. The late Mr. W. R. Birt, however, continued it for a time.

A wax model of the whole lunar surface was executed many years ago by a Hanoverian lady named Witte, and Nasmyth has modelled in plaster of Paris several single craters[g]. Photography, too, has been called in by De La Rue, Rutherford, and others, with good results.

In computing the places of the Moon the Tables of Burckhardt, published in 1812, were formerly used, but in 1862 the new and more perfect Tables of Hansen were introduced at the *Nautical Almanac* office; and these have entirely superseded Burckhardt's. Damoiseau, Plana, Carlini, Pontécoulant, Lubbock, and afterwards Delaunay, in addition to Hansen, did much to improve the theory of the Moon. Delaunay's labours earned for him a foremost place in the rank of geometrical astronomers. More recently still, Sir G. B. Airy has been treating the subject by a new method. His memoir entitled the "Numerical Lunar Theory" was published in 1887. He is understood to be still investigating some points in it which need further elucidation[h].

According to a recent determination by Stone the Moon's mass is $\frac{1}{81 \cdot 36}$ that of the Earth.

To record a tithe of the influences ascribed to the Moon would be a herculean task; nevertheless (in addition to the tides) one

[g] Fig. 65 is from a photograph of one of these. But they are of little value, being very inexact.

[h] *Month. Not.*, vol. xxxiv. p. 89. Jan. 1874.

deserves notice. Evening clouds at about the period of Full Moon will frequently disperse as our satellite rises, and by the time it has reached the meridian a sky previously overcast will have become almost or quite clear. I first observed this in 1857, and *subsequently* found that Sir J. Herschel[i] had made the same remark. The idea has been disputed[k], but I am firmly convinced of its truth. Humboldt speaks of it as well known in South America, and Arago indirectly confirms the theory when he shows that more rain falls at about the time of New Moon (*cloudy period*) than at the time of Full Moon (*cloudless period* according to the theory). According to Forster, Saturday new Moons result in 3 weeks of wet weather. He alleged that observations extending over 80 years showed this coincidence[l]. Bernadin asserts it as a fact that many thunderstorms occur about the period of New or Full Moon. With these possible exceptions it is safe to assert that "changes" of the Moon have no discoverable influence on the weather[m].

[i] *Outlines of Ast.*, p. 285.

[k] Ellis, *Phil. Mag.*, 4th Ser., vol. xxxiv. p. 61. July 1867.

[l] *Month Not.*, vol. ix. p. 37. Dec. 1848.

[m] See Nasmyth and Carpenter, *Moon*, p. 180.

CHAPTER VIII.

THE ZODIACAL LIGHT.

General description of it.—When and where visible.—Sir J. Herschel's theory.—Historical notices.—Modern observations of it.—Backhouse's Conclusions.

ASTRONOMICAL writers are not agreed as to the proper head under which to describe and discuss the Zodiacal Light. I deal with it here, because, whatever its origin, it is a matter of terrestrial cognizance, and therefore a description of it may, without any serious incongruity, be associated with what has to be said about the Earth.

The Zodiacal Light is a peculiar nebulous light of a conical or lenticular form [a], which may very frequently be noticed in the evening soon after sunset about February or March, and in the morning before sunrise about September. It extends upwards from the Western horizon in the spring and from the Eastern horizon in the autumn, and generally, though by no means always [b], its axis is nearly in a line with the ecliptic, or, more exactly, in the plane of the Sun's equator. The apparent angular distance of its vertex from the Sun's plane varies, according to circumstances, between 50° and 70°; sometimes it is more; the breadth of its base, at right angles to the major axis, varies between about 8° and 30°. During its evening apparition it usually reaches to a point in the heavens situated not far from the Pleiades in Taurus. It is always so extremely ill-defined at

[a] *Lens,* a lentil. [b] *Month. Not.*, vol. xxx. p. 151. March 1870, *et infra.*

the edges that great difficulty is experienced in satisfactorily determining its limits. In Northern latitudes the Zodiacal Light is generally, though not always, inferior in brilliancy to the Milky Way; but in the Tropics it is seen to far greater advantage. Humboldt said that it is almost constantly visible in those regions, and that he himself had seen it sufficiently luminous to cause a sensible glow on the opposite quarter of the heavens [c]. In the winter of 1842–43 it was remarkably well seen in this country, the apex of the cone attaining a length of no less than 105° from the Sun [d]. Lassell also mentions having seen the light very conspicuous at Malta in January 1850 [e].

No satisfactory explanation has yet been given of this phenomenon; it is, however, very generally considered to be a kind of envelope surrounding the Sun, and extending perhaps nearly or quite as far as the Earth's orbit. Sir J. Herschel's opinion was "that it may be conjectured to be no other than the denser parts of that medium which we have some reason to believe resists the motion of comets; loaded, perhaps, with the actual materials of the tails of millions of those bodies, of which they have been stripped in their successive perihelion passages [!!]. An *atmosphere* of the Sun, in any proper sense of the word, it cannot be; since the existence of a gaseous envelope propagating pressure from part to part—subject to mutual friction in its strata, and thereby rotating in the same, or nearly the same, time with the central body, and of such dimensions and ellipticity—is utterly incompatible with dynamical laws [f]." In connexion with this speculation it may be mentioned that during the visibility of the great comet of 1843 in March of that year, the Zodiacal Light was unusually brilliant; so much so, that by many persons it was mistaken for the comet.

The Zodiacal Light is of a reddish hue, especially at its base,

[c] But on this point see Humboldt's later statement on p. 145, *post.*

[d] Detailed particulars will be found in the *Greenwich Observations*, 1842.

[e] For observations by E. J. Lowe, see *Month. Not.*, vol. x. p. 124, March 1850; vol. xi. p. 132, March 1851; and vol. xiv. p. 16, Nov. 1853. Observations by Burr and Webb will be found at pp. 45, 83, and 181 of the same volume; and see a paper by T. Heelis in *Mem. of the Lit. and Phil. Soc. of Manchester*, 3rd Ser., vol. ii. p. 437, 1865.

[f] *Outlines of Ast.*, p. 658.

where also it is most bright, and where it effaces small stars. Undulations and likewise a sort of flashing have been noticed in it.

It has been suggested that the Zodiacal Light is identical with what Pliny and Seneca call the "Trabes [g]," but more likely this was the Aurora.

The Zodiacal Light was treated of by Kepler; afterwards by Descartes, about the year 1630; and then by Childrey, in 1659 [h]; it was not, however, till J. D. Cassini, who saw it first on March 18, 1683, published some remarks on this phenomenon that much attention was paid to it [i].

In the year 1855, the Rev. G. Jones, Chaplain of the U. S. Steam-Frigate *Mississippi*, published some remarks on this phenomenon [k], as brought under his notice during a cruise round the world in the 2 preceding years. He stated:—"I was also fortunate enough to be twice near the latitude of 23° 28′ North, when the Sun was at the opposite solstice, in which position the observer has the ecliptic at midnight at right angles with his horizon, and bearing East and West. Whether this latter circumstance affected the result or not, I cannot say; but I there had the extraordinary spectacle of the Zodiacal Light simultaneously at both East and West horizons from 11 to 1 o'clock for several nights in succession."

Mr. Jones concluded his very interesting letter as follows:—"You will excuse my prolixity in stating these varieties of observations, for the conclusion from all the data in my possession is a startling one. It seems to me that those data can be explained only by the supposition of *a nebulous ring with the Earth for its centre, and lying within the orbit of the Moon* [l]."

On the publication of the foregoing, Humboldt transmitted to

[g] *Hist. Nat.*, lib. II. cap. 26.

[h] *Natural History of England*, 1659. *Brit. Bacon.*, p. 183. 1661.

[i] *Anc. Mém. de l'Acad. des Sciences*, vol. viii. p. 121.

[k] Gould's *Astronomical Journal*, No. 84, May 27, 1855. In the *Month. Not.*, vol. xvii. pp. 204–5, May 1857, are some distrustful remarks on this communication, to which the reader should refer, and at p. 47 is some account of J. F. J. Schmidt's work on the Zodiacal Light.

[l] See Jones's original memoir in vol. iii. of the 4to. ed. of the U. S. Exploring Expedition *Narrative*. (Washington, 1856.)

the Berlin Academy[m] some unpublished observations made by him at sea in March 1803, to the effect that on one or two occasions he also saw a 2nd light in the East contemporaneously with the principal beam in the West; he, however, *then* thought that the 2nd light was merely due to reflection. He concludes by saying that "the variations in the brightness of the phenomenon cannot, according to my experience, be accounted for solely by the constitution of our atmosphere. There remains much still to be observed relative to the subject."

Jones seems in one sense to have been anticipated in his "double end" view of the Zodiacal Light, as will appear from the following extract, which is here cited for a twofold purpose:—"The two extremities of the Zodiacal Light may be seen on the same night about the time of the solstices, particularly the Winter solstice, when the ecliptic makes, night and morning, nearly equal angles with the horizon, and these are sufficiently great to allow a considerable portion of the points of the light to appear above the line of the twilight. It is thus that it was observed by Cassini on Dec. 4, 1687, at $6^h\ 30^m$ P.M. and $4^h\ 40^m$ A.M. the following morning[n]."

Capt. C. Wilkes of the U.S. Exploring Expedition controverted Jones's views on many material points, and regarded the Zodiacal Light as the result of the illumination of that portion or section of the Earth's atmosphere on which the rays of the Sun fall perpendicularly in the Tropics[o].

Jones's observations have been subjected to a very painstaking and searching review by Searle, whose conclusions, embodying as they do the observations of others besides Jones, may be thus brought to a focus:—(1) The Secondary (or opposite) Light (called by the Germans "Gegenschein") is an undoubted fact, and its connection with the main Light highly probable; (2) That the Zodiacal Light lies further to the N., near the Autumnal

[m] *Monatsbericht der Kön. Preuss. Akademie der Wissenschaften*, July 26, 1855, p. 517. *Month. Not.*, vol. xvi. p. 16. Nov. 1855.

[n] J. R. Jackson, *What to Observe*, 2nd ed., p. 106.

[o] *Theory of the Zodiacal Light*, p. 12. A Paper read at the Montreal Meeting of the American Association for the Advancement of Science, 1857.

than it does near the Vernal Equinox, is also highly probable; (3) Atmospheric absorption largely affects the apparent positions of the Zodiacal Light; (4) The belt of sky occupied by the projections of the first 237 Minor Planets presents certain peculiarities which correspond to those of the Zodiacal Light, and suggest that it may be partly due to minute objects circulating in planetary orbits [p]; (5) The Light does not interfere with the visibility even of small stars [q]; (6) The final disappearance of the Light occurs by its setting rather than by its fading [q].

Heelis considers that his observations, made in 1862 on board ship in the Tropics, point to the change of position in the Light as depending on the time of year more than on the observer's place of observation.

The most extensive recent observations on this subject which are of value are those made in the years 1869–71 by Colonel Tupman in the Mediterranean. He confirms on many points previous observers, but contradicts them on one very important point. He asserts that the plane of the Light *does not pass through the Sun*. He also remarks having noticed great want of uniformity in the position of the axis of symmetry with respect to the ecliptic. In August and September the axis is frequently inclined as much as 20° to the ecliptic, whilst in the winter it is sensibly parallel to the ecliptic [r].

On December 19 and 20, 1870, when in Sicily, whither he had gone to observe the solar eclipse, Mr. A. C. Ranyard and some friends (Secchi amongst them) examined the Zodiacal Light through a Savart polariscope. His main conclusion is, that the Zodiacal Light consists of matter which reflects the Sun's light. He adds, that such matter either (1) exists in particles so small that their diameters are comparable with the wave lengths of light, or (2) is matter capable of giving specular reflection [s].

Some observations by Birt are not unworthy of attention. They were made chiefly in 1850, though a few of his notes refer

[p] *Mem. Amer. Acad.*, vol. xi. p. 157, 1885.

[q] *Proc. Amer. Acad.*, vol. xix. pp. 156, 163.

[r] *Month. Not.*, vol. xxxii. p. 74. Jan. 1872.

[s] *Month. Not.*, vol. xxxi. p. 171. March 1871.

to April 1871. Birt drew attention to two special points:— (1) The fact that the greater portion of the Light always lies to the N. of the ecliptic; and (2) That comparing the shape of the cone of light month by month from February to April it becomes progressively more and more blunt, so much so "as to lead to the suspicion that we view the phenomenon differently as the Earth advances in her orbit from the point at which we beheld it in the winter months[t]."

Little or no progress has been made during recent years in elucidating the theory of the Zodiacal Light: and this is the more remarkable considering the development of all other branches of Astronomy. Backhouse published in 1881 the results of 418 observations between 1867 and 1877, chiefly directed to a determination of the Light's Inclination to the ecliptic[u]. His deductions, though based on so large a series of data, are not very conclusive. He finds the average deviation of the axis of the Light from the plane of the ecliptic to be 2°, and the Longitude of the Ascending Node, 35°.

A Dutch observer, Gronemann, after giving much attention to the matter, has pronounced against the solar theory of the Zodiacal Light; he considers it to have a terrestrial origin. His main contention is that the affirmed connection between the evening and morning cones of light is not established, and that the participation of the cones in the daily motion of the heavens is likewise not proved to be a fact[x].

Serpieri, the Director of the Meteorological Observatory at Urbino, communicated to the Italian Spectroscopic Society in 1876 a very elaborate memoir on the Zodiacal Light, summing up all the results of previous observers[y]. He would see in the phenomenon an electrical origin.

[t] *Month. Not.*, vol. xxxi. pp. 177–82. April 1871.

[u] *Month. Not.*, vol. xli. p. 333. May, 1881.

[x] *Archives Néerlandaises.*

[y] *Memorie degli Spettr. Italiani*, vol. v. 1876.

CHAPTER IX.

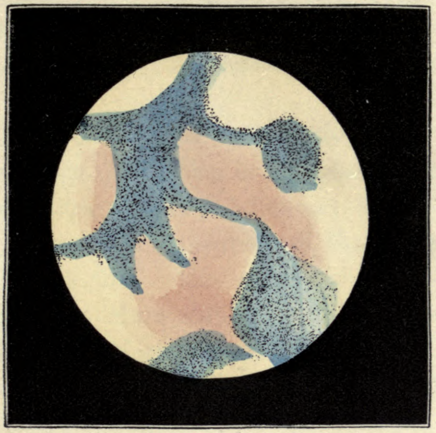
MARS[a]. ♂

Period, &c.—Phases.—Apparent motions.—Its brilliancy.—Telescopic appearance.—Its ruddy hue.—Schiaparelli's "Canals."—General statement of the physical details of Mars.—Map of Mars on Mercator's projection.—Polar snow.—Axial rotation.—The seasons of Mars.—Its atmosphere.—The Satellites of Mars.—Ancient observation of Mars.—Tables of Mars.

MARS is the first planet exterior to the Earth in the order of distance from the Sun, and, as we shall presently see, bears a closer analogy to it than do any of the other planets.

Mars revolves round the Sun in $686^d\ 23^h\ 30^m\ 41^s$, at a mean distance of 141,536,000 miles, which an orbital eccentricity of 0·093 may augment to 154,714,000 miles, or diminish to 128,358,000 miles. The apparent diameter of Mars varies between 4·1″ in conjunction and 30·4″ in opposition; and owing to the great eccentricity of the orbit of Mars its apparent diameter as seen from the Earth will vary much at different oppositions. The diameter at mean distance of the planet from the Earth being 7·28″ (Le Verrier), the real diameter is nearly 5000 miles. Very varying results have been arrived at as to the compression of Mars. Sir W. Herschel gave it at $\frac{1}{16}$; Schröter contradicted this, and asserted that it must be less than $\frac{1}{80}$; Bessel merely decided that it was too

[a] Observers interested in Mars should consult a valuable memoir entitled *Areographie* presented to the Académie Royale de Belgique in June 1874 by F. Terby of Louvain. It is the most exhaustive account of the planet which has ever appeared. A fine series of lithographic views by N. E. Green will be found in *Mem.* R.A.S., vol. xliv. p. 123, 1879.



1858 : June 3.

1858 : June 14.

MARS.

(*Drawn by Secchi.*)

small for measurement with his great heliometer at Königsberg[b]; Arago from Paris observations extending over 36 years (from 1811 to 1847) deduced $\frac{1}{30}$. Hind considers that $\frac{1}{51}$, and Main that $\frac{1}{39}$ is not very far from the truth. Kaiser's $\frac{1}{114}$ confirms Schröter.

Mars exhibits phases, but not to the same extent as the inferior planets. In Opposition it is perfectly circular; between this and the quadratures it is gibbous; and at the minimum phase, which occurs at the quadratures, the planet resembles the Moon 3^d from the full. The character of these phases is a sufficient proof that Mars shines by the reflected light of the Sun. The phases of Mars were discovered by Galileo, who on Dec. 30, 1610 wrote to Castelli, "I dare not affirm that I can observe the phases of Mars; however, if I mistake not, I think I already perceive that he is not perfectly round."

After Conjunction, when Mars first emerges from the Sun's rays, it rises some minutes before the Sun, and has a direct or Easterly motion; but since this motion is only half that of the Earth in the same direction, Mars appears to recede from the Sun in a *Westerly* direction, notwithstanding that its real motion among the stars is towards the East. This continues for nearly a year, and ceases when its angular distance from the Sun amounts to about 137°; then for a few days it appears stationary. After that, its motion becomes retrograde, or Westerly among the stars, and continues so until the planet is 180° distant from the Sun, or in Opposition, and consequently on the meridian at midnight. At this period its retrograde motion is swiftest; it afterwards becomes slower, and ceases altogether when the planet is again at a distance of about 137° on the other side of the Sun. Its motion then again becomes direct, and continues so, till once more the planet is lost in the solar rays, when the phenomena are renewed, but with a considerable difference in the extent and duration of the movements. The retrogradation commences or finishes when the planet is at a distance from the Sun which varies from 128° 44′

[b] See his memoir in *Ast. Nach.*, vol. xxxv. p. 351. Dec. 17, 1852.

to 146° 37′, the arc described being from 10° 6′ to 19° 35′; the duration of the retrograde motion in the former case is $60^d\ 18^h$, and in the latter $80^d\ 15^h$. The period in which all these changes take place, or the interval between 2 Conjunctions and 2 Oppositions, constitutes the synodical period, which amounts to 780^d. Mars and the Earth come *nearly* to the same relative position every 32^y; but several centuries elapse before precise coincidence occurs [c].

Mars when in Opposition is a very conspicuous object in the heavens, shining with a fiery red light, which from its striking character has led to the planet being celebrated throughout the historic period. It received from the Jews on this account an epithet equivalent to "blazing," and the Greek one (*πυρόεις*) bears much the same meaning. Its name or epithet in many other languages is substantially the same.

Its synodic period being 780 days, it comes to Opposition and therefore attains its (general) maximum brilliancy, once in rather more than 2^y. When in perihelion and in perigee at the same time, which occurs once in 7 synodical revolutions ($14^y\ 11\frac{1}{2}^m$), Mars shines with a brilliancy rivalling that of Jupiter. In August 1719, the planet being only 2½° from perihelion, its brightness was such as to cause a panic [d]. The most favourable Oppositions are those which occur on or about August 26; and the least favourable those which occur about Feb. 22. Favourable Oppositions will occur in 1892 and 1909.

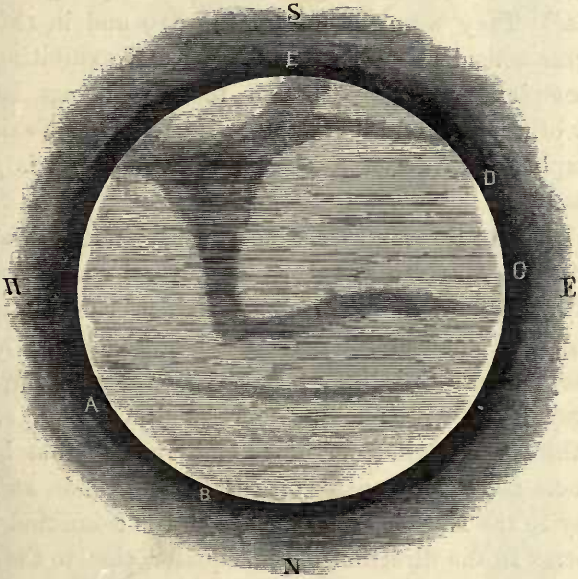
With suitable optical assistance, Mars is found to be covered with dusky patches, which have been supposed, and with good reason, to be continents analogous to those of our own globe: these are of a dull red blue; other portions, of a greenish hue, are believed to be tracts of water. The ruddy colour, which, overpowering the green, gives the tone to the whole of the planet, was believed by Sir J. Herschel to be due to "an ochrey tinge in the general soil, like what the red sandstone districts on the Earth may possibly offer to the inhabitants of Mars, only

[c] Smyth, *Cycle of Celest. Objects*, vol. i. pp. 151–2,—abridged and corrected.

[d] De Zach, *Corr. Astronomique*, vol. ii. p. 293. March 1819.

more decided[e]." In a telescope Mars appears less red than to the naked eye, and according to Arago[f] the higher the power the less the intensity of the colour. Webb writes:—"The disc, when well seen, is usually mapped out in a way which gives at once the impression of land and water, the outlines, under the most favourable circumstances, being extremely sharp: the

Fig. 76.



MARS, APRIL 18, 1856. (*Brodie.*)[g]

bright part is orange,—according to Secchi, sometimes dotted with red, brown, and greenish points; sometimes found by Schiaparelli filled with a complete network of their lines and minute interspaces; the darker regions, which vary greatly in depth of tone, are in places brownish, but more generally of a dull grey-green (or, according to Secchi, bluish tint), possessing the aspect of a fluid absorbent of the solar rays. If so, the proportion of land to water is considerably greater on Mars than on the Earth; so that the habitable area may possibly be

[e] *Outlines of Ast.*, p. 339.
[f] *Pop. Ast.*, vol. ii. p. 483. Eng. ed.
[g] *Month. Not.*, xvi. p. 205. June 1856.

much more alike than the diameter of the planets. The water however (if such it be) is everywhere in communication, and long narrow straits are more common than on the Earth[h]."

In 1877, when Mars was in a part of its orbit favourable for observation, Schiaparelli at Milan detected a number of minute dusky bands, for the most part very narrow and straight, traversing and cutting up the supposed continents in various directions. These markings are commonly spoken of as "Canals." They were seen again in 1879 and in 1882, in the latter year considerably more numerous and exhibiting a much more complex network. Though these markings have been seen by other observers it cannot be said that their existence in the sharply defined forms suggested by Schiaparelli is generally recognisable.

The details of this planet are not readily seen with an instrument of small aperture, yet there are several features which are well within the powers of a 4-inch refractor or 6-inch reflector.

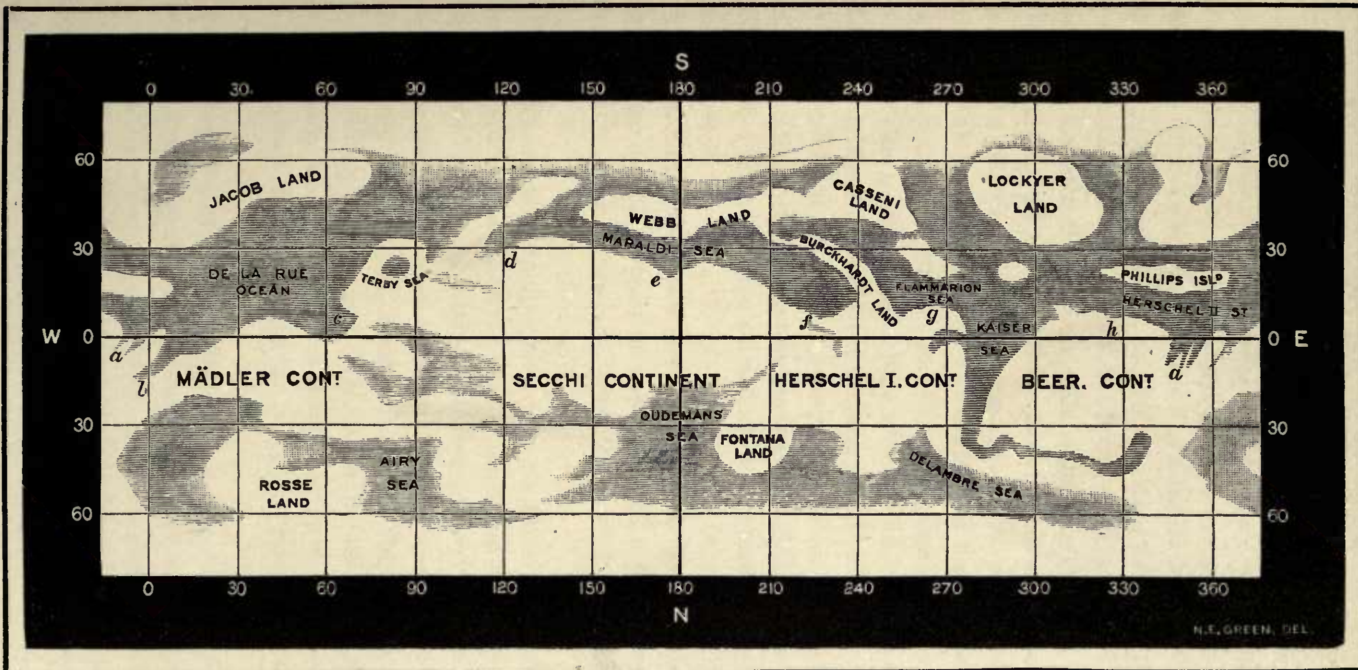
The general tone of the disc is a reddish orange, and on it there may be seen certain gray markings, the most important of these being the "Kaiser Sea" in longitude 285°, sometimes called the "V" mark, from its resemblance to that letter. It commences above the equator on the Southern side, and extends half way to the N. pole. The Kaiser Sea is connected with two dark forms in the direction of the equator, that to the E. being called "Herschel II." Strait, and that on the W. Flammarion Sea. This large dark form cannot be mistaken, and if a telescope will show anything on the planet it will show this.

It should be observed that the apparent form of the Kaiser Sea differs greatly at different oppositions of Mars, in consequence of the varying view we have of the poles. When the S. pole is towards the Earth, Kaiser Sea is considerably foreshortened; whereas when the N. pole is towards the Earth, it is elongated.

Herschel II. Strait extends on the E. to the equator, where it terminates in a well-known mark, the *a* of Beer and Mädler, from

[h] *Celest. Objects*, 4th ed. p. 141.

Fig. 77. | *Plate* **X.**



MARS ON MERCATOR'S PROJECTION.

a. Dawes's forked Bay.
b. Burton Bay.
c. Christie Bay.
d. Pratt Bay.
e. Trouvelot Bay.
f. Huggins Bay.
g. Main Sea.
h. Schmidt Bay.

which Martial longitudes are reckoned. This mark was discovered by Dawes to be composed of two points, as shown in the map, and it is appropriately named after that observer.

Between Dawes's forked bay and the next dark point, Burton Bay, there is generally seen a space connecting the light portions of the equatorial region with Phillips Island to the S.; but this was filled with shade during the opposition of 1877.

When Burton Bay has passed the meridian, a large dark mark, called De La Rue Ocean, extends towards the S. pole, its Eastern extremity being Christie Bay. On the S.E. of De La Rue Ocean may be seen a well-defined round dark spot named Terby Sea in the map. This mark is difficult to observe during those oppositions, when the N. pole is directed towards the Earth.

When Terby Sea has passed, a long dark streak, called Maraldi Sea, comes into view, and continues till Flammarion Sea heralds Kaiser Sea, with which we started, thus completing the circuit of the planet.

The polar snow-spots are seen with great distinctness when Mars is approaching Opposition; from that time they decrease in size, till it requires sharp and educated vision to detect their presence.

There is a round orange spot in the Southern hemisphere in longitude 300°, called Lockyer Land. This was seen during the Opposition of 1873 to be white as though covered with snow. A similar, though smaller spot exists in the Northern hemisphere at 210° of longitude, named Fontana Land. The details of the Northern hemisphere are not only less important than those of the Southern, but are the less known in consequence of the greater distance of Mars when the N. pole is turned towards the Earth.

One point of contrast there is between Mars and the Earth. Whereas on the Earth the proportion of water to land is about 11 to 4, on Mars the proportions are probably about equal. It is to be noted also that the water on Mars is for the most part disposed in long narrow channels; of wide expanses of water, such as our Atlantic Ocean, there are few.

In the vicinity of the poles brilliant white patches may be noticed, which are now considered by astronomers to be masses of snow—an idea which is materially strengthened by the fact that they have been observed to diminish when brought under the Sun's influence at the commencement of the Martial summer, and to increase again on the approach of winter.

The observation of these white patches appears to date from the middle of the 17th century, for they seem to be noticed in a figure of the planet by Huygens; Maraldi, in 1704, first gave specific representations of them. Sir W. Herschel[i], who discovered tho circumstances attending their variation in size, found that they were not always precisely opposite, both being sometimes visible or invisible at the same time. Mädler noted the S. polar spot to undergo greater changes of magnitude than the Northern one, an observation harmonising with the fact that from the eccentricity of the planet's orbit it experiences a greater variety of climate. The same observer found (and herein he was confirmed by Secchi) the N. patch concentric with the planet's axis, but the S. one considerably eccentric, which agrees substantially with Sir W. Herschel's observation. It is not easy to understand why they are not exactly opposite; if both were equally removed, and in opposite directions, from poles of rotation, it would occur, as with the Earth, that the poles of cold differed from those of rotation, but the subsisting facts are inexplicable.

Figs. 78–79 represent the Polar snows of Mars as drawn by Mr. N. E. Green, an observer who has paid much attention to this planet[j].

It will be seen that in Fig. 78 there is on the west side of the Polar cap a detached point of light. Green regarded this as a patch of snow which rested on elevated ground after the snow had melted on the lower levels. This light was afterwards seen on Sept. 8 and 10.

On Sept. 8, however, 2 patches were visible, and on Sept. 10

[i] *Phil. Trans.*, vol. lxxiv. p. 2 *et seq.* 1784.
[j] *Mem.* R.A.S., vol. xliv p. 126.

a faint line of points concentric with the zone of snow. The observer thought that these alterations of form were in all

Fig. 78.

THE SOUTH POLE OF MARS, SHOWING SNOW. Sept. 1, 1877. (*Green.*)

probability due to perspective; the single point of Sept. 1 appearing as two when less foreshortened, and that these when

Fig. 79.

THE SOUTH POLE OF MARS, SHOWING SNOW. Sept. 8, 1877. (*Green.*)

still further separated appeared still further increased in numbers as they were seen nearer the central meridian of the disc. Green further suggests that—

"This brilliant appearance of the spots when most to the West of the pole, and their decrease in brilliance when passing the meridian, together with the most significant fact that they were not seen at all on the Eastern side, can best be explained by supposing the slopes of the hills that retained the snow to have a South-westerly aspect; they would thus be sheltered from the Sun's rays during the greater part of a revolution, but fully exposed to its light, and therefore better seen, just as they were passing away towards the Western limb."

Spots on the body of Mars led at an early period to attempts being made to ascertain the period of its axial rotation. J. D. Cassini, in 1666, found this to be effected in $24^h 40^m$; Hooke[k], working contemporaneously, was unable to decide between 12^h and 24^h. Mädler[l] fixed the time of revolution at $24^h 37^m 23^s$,—a result which singularly accords with Cassini's, and says much for the accuracy and skill of the astronomer of Bologna. Drawings by Hooke and by Huygens more than 200 years old have been turned to account in modern times to throw light upon the rotation of Mars. Using some of Huygens's sketches, Kaiser was led to fix the period of Mars at $24^h 37^m 22{\cdot}62^s$; Proctor[m], using some of Hooke's sketches, obtained as the result $24^h 37^m 22{\cdot}71^s$. The most recent observations, resting on a prolonged basis, are those of Denning, who from 15 years' observations ending in 1884 obtained a period of $24^h 37^m 22{\cdot}34^s$. Sir W. Herschel's figures were $24^h 39^m 21{\cdot}67^s$; he stated, though on wholly insufficient data, that the obliquity of the ecliptic on Mars was 28° 42′—an angle so close to that which obtains for the Earth, as, if confirmed, to warrant us in asserting that the seasons of Mars are not materially different from our own.

The Martial year consists of 668 Martial days and 16 hours, the Martial day being longer than the terrestrial in the proportion of 100 to 97. Owing to the eccentricity of the planet's orbit, the summer half of the year in the Northern hemisphere consists of 372 days, and the winter half of 296 days. As a matter of course, the reverse state of things prevails in the Southern hemisphere; there the winter half-year consists of 372 days and the summer of 296 days. Nevertheless, although the extremes of temperature may, and probably do, differ widely in the two

[k] *Phil. Trans.*, No. 14, p. 244. July 2, 1666.
[l] *Ast. Nach.*, vol. xv. No. 349. April 7, 1838.
[m] *Month. Not.*, vol. xxxiii., p. 558. 1873.

hemispheres, the mean temperatures of each may possibly differ but little. The duration of the seasons in Martial days in the Northern hemisphere is as follows:—Spring 191, summer 181, autumn 149, winter 147. For the Southern hemisphere we must reverse the seasons: this being done, it will appear that spring and summer taken together are 76 days longer in the Northern hemisphere than in the Southern.

The observations of Cassini led to the belief that Mars possessed a very extensive atmosphere: this has not been confirmed, and it is now only admitted that Mars has an atmosphere which is moderately dense. Sir J. South, who paid much attention to this subject, stated that he had seen one star in contact with the planet and 2 occulted without change; thus overthrowing an opinion which resulted from an assertion of Cassini's that ψ Aquarii (a star of the 5th mag.) on one occasion, in Oct. 1672, disappeared in a 3-feet telescope when 6′ from the planet's limb. But was the planet gibbous at the time?

In former editions of this work it was stated that "Mars possessed no satellite, though analogy does not forbid, but rather, on the contrary, leads us to infer the existence of one; and its never having been seen, in this case at least, proves nothing."

In the year 1877 an able American observer, Asaph Hall disproved the first part of this statement, and confirmed the closing inference. The Opposition of Mars in 1877 promised by reason of the situation of the planet in the heavens to be a very favourable one, and Hall conceived the idea that, having the command of the fine refractor of the Washington Observatory (aperture, 26 inches), he might perhaps be fortunate enough to detect a satellite if Mars had one. Independently of the promising circumstances just mentioned, Hall had hopes that some favourable result might come of his effort because, with the exception of an attempt made by D'Arrest at Copenhagen in 1862 (or 1864), no systematic search for a Martial satellite had been made since Sir W. Herschel's failure as far back as 1783. Hall began his search early in August 1877. At first he found near the planet only some small stars; but on the night of August 11 he detected a faint object on the *nf.* side of the planet which afterwards proved to be the outer satellite. Bad weather hindered him until August 16, when a small object was again seen which the observations of that night showed to be a satellite in motion with the planet and near one of its Elongations. On August 17, while waiting and watching for the satellite first seen (the outer one), he discovered a second (the inner one). Further observations on the following night placed beyond doubt the character of the two objects and their discovery was publicly announced. Nevertheless for several days Hall was much puzzled by the apparent motions of the inner moon. It seemed to appear on different sides of the planet the same night, and he at first thought there must be 2 or 3 satellites within the orbit of the outer one, since it seemed so unlikely that a satellite should revolve round its primary in less time than the primary rotated on its axis. In order to decide the point the inner satellite was watched throughout the nights of August 20 and 21, by which means it was clearly ascertained that there was but one inner satellite, and that revolving round its primary in less than $\frac{1}{3}$rd of the time of the primary's own axial rotation—a case unique in the solar system.

When the discovery of these satellites was made public various observatories took up the matter, and between August and the end of October 1877, that is to say, so long as Mars remained favourably placed for observation, the satellites were seen at several of the larger public observatories in Europe and America, and likewise at the private observatories of Mr. A. A. Common, Ealing, England, and Mr. W. Erck, Sherrington, near Bray, Ireland. At the Opposition of 1879 these satellites were both again observed in America, as also in 1881, but in the latter year observations were few, Mars not being very favourably placed for the purpose.

At the suggestion of Mr. Madan, of Eton, the outer satellite was named by the discoverer "Deimos" and the inner satellite "Phobos"; these being the mythological names of the horses which drew the chariot of Mars, although by Homer personified and meaning the attendants of Mars.

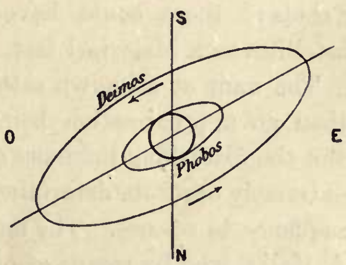
> "He spake and summoned Fear and Flight to yoke
> His steeds, and put his glorious armour on [n]."

Considering the small size of these satellites it will not be expected that much information can be given respecting them.

Phobos revolves round Mars in 7^h 39^m at a distance of about 6000 miles. Hall thinks the orbit may have a slight eccentricity. The angular amount of the maximum distance from the planet is about 12″; and the brightness at Opposition is about that of a star of mag. $11\frac{1}{2}$.

Deimos revolves round Mars in 30^h 18^m at a distance of about 15,000 miles. The orbit is almost circular. The angular amount of the maximum distance from the planet is about 32″, and the brightness at Opposition is about that of a star of mag. $13\frac{1}{2}$.

Fig. 80.



THE APPARENT ORBITS OF THE SATELLITES OF MARS.

The planes of the orbits of both satellites are very nearly coincident with the equator of Mars. The hourly areocentric motion of Phobos is 47°, and on account of its rapid motion and its nearness to the planet this satellite must present a very singular appearance to an observer on Mars. It will rise in the W. and set in the E.[o] and will meet and pass Deimos, whose hourly areocentric motion is only 11·8°. The semi-diameter of Mars being 2100 miles, the horizontal parallaxes of these satellites are very large, amounting to 21° for Phobos. The nearness of this satellite to the surface of the planet will produce apparent singularities in its motion, and cause it to appear as a variable star. Some photometric observations by

[n] Homer, *Iliad*, lib. xv. Bryant's Translation.

[o] The *rationale* of this is explained at length in the Rev. E. Ledger's *The Sun and its Planets*, p. 253; where will also be found some other speculations as to the phenomena connected with these satellites.

Pickering imply that Phobos has a diameter of 7 miles and Deimos of 6 miles [p].

It is interesting to note that there is extant a copy of a letter by Kepler to his friend Wachenfels, written shortly after the announcement of Galileo's discovery of the satellites of Jupiter, in which Kepler expresses his eagerness for a telescope wherewith to discover 2 satellites for Mars, that being the number which "proportion seems to require [q]."

Dean Swift, too, in *Gulliver's Travels* [r] speaks of the astronomers of Laputa having done more than the astronomers of Europe, for "They have likewise discovered 2 lesser stars or satellites which revolve about Mars." And Voltaire, in his romance of *Micromegas*, speaking of some of his characters says: "Ils virent deux lunes qui servent à cette planète [Mars] et qui ont échappé aux regards de nos astronomes." But of course these are nothing but happy "shots;" there could have been no tradition of 2 Martial satellites as a historical fact.

The want of a known satellite long prevented anything more than an approximation being arrived at of the mass of Mars. But the disturbing influence of this planet being insignificant, an extremely accurate determination of its mass is of no great consequence to science. The most trustworthy value appears to be A. Hall's, who by means of observations of the two satellites has obtained the figures $\frac{1}{3093500}$.

"The most ancient observation of Mars that has come to our knowledge is one reported by Ptolemy in his *Almagest* (lib. x. cap. 9). It is dated in the 52^{nd} year after the death of Alexander the Great, and 476^{th} of Nebonassar's era, on the morning of the 21^{st} of the month *Athir*, when the planet was above but very near the star β in Scorpio. The date answers to B.C. 272, Jan. 17, at 18^{h} on the meridian of Alexandria. An occultation [s] of the planet

[p] The foregoing particulars are chiefly from A. Hall's *Observations and Orbits of the Satellites of Mars*, Washington, 1878, a memoir issued by the U. S. Naval Observatory.

[q] Brewster, *Life of Kepler.*

[r] Part III. ch. iii.

[s] Inasmuch as the apparent diameter of Mars is (except under rare circumstances) less than that of Jupiter, the more correct expression would probably be "a transit of Mars across Jupiter," &c.

Jupiter by Mars on Jan. 9, 1591, is recorded. Such a phenomenon would be extremely interesting if viewed with the powerful telescopes so common at the present day[t]."

In computing the places of Mars the tables of Baron De Lindenau, published in 1811, were generally used until recently, but they were superseded in 1861 by the more perfect tables of Le Verrier[u].

[t] Hind, *Sol. Syst.*, p. 79.

[u] *Annales de l'Observatoire de Paris, Mém.*, vol. vi., Paris, 1861.

CHAPTER X.

THE MINOR PLANETS[a].

Sometimes called Ultra-Zodiacal Planets.—Summary of facts.—Notes on Ceres.—Pallas.—Juno.—Vesta.—Olbers's theory.—History of the search made for them.—Independent discoveries.—Progressive diminution in their size.

BETWEEN the orbits of Mars and Jupiter there is a wide interval, which, until the present century, was not known to be occupied by any planet. The researches of late years, as previously intimated in Chapter II., have led to the discovery of a numerous group of small bodies revolving round the Sun, which are known as the Minor Planets[b], and which have received names taken at the outset chiefly from the mythologies of ancient Greece and Rome, but in recent years from all sorts of sources[c], many names being most fantastic and ridiculous.

These planets differ in some respects from the other members of the system, especially in point of size, the largest being probably not more than, even if so much as, 200 miles or 300 miles in diameter. Their orbits are also, as a general rule, much more inclined to the ecliptic than the orbits of the major planets, for which reason it was once proposed to term them the *Ultra-*

[a] The use of symbols has been discontinued, except for the four early ones, as follows: Ceres ⚳, Pallas ⚴, Juno ⚵, Vesta ⚶; and even these are becoming obsolete. Gould's suggestion to adopt by way of symbol the number in the order of discovery enclosed in a circle thus: (54), has been universally adopted.

[b] The old name of *asteroids*, proposed by Sir W. Herschel, has nearly fallen into disuse. Such a designation was not very appropriate; *planetoids* would have been better. However, *minor planets* is preferable to either.

[c] The names *Lumen*, *Bertha*, and *Zelia*, assigned by MM. Henry, are said to commemorate members of the family of the French astronomer Flammarion, a characteristic specimen of the French way of doing things.

Zodiacal Planets: and many orbits are eccentric to a degree for which no parallel can be found amongst the major planets.

It is needless to give any detailed account of each, but a short summary may not be out of place[d].

The nearest to the Sun is *Medusa* (149), which revolves round that luminary in 1139^d, or $3{\cdot}1^y$, at a mean distance of 198,134,000 miles. Next come *Sita* (244), and *Anahita* (270).

The most distant is *Thule* (279), whose period is 3220^d, or $8{\cdot}8^y$, and whose mean distance is 396,454,000 miles. Next come *Hilda* (153), *Ismene* (190), and *Andromache* (175). The last-named recedes farthest from the Sun of any owing to the great eccentricity of its orbit.

The least eccentric orbit is that of *Philomela* (196), in which ϵ amounts to only 0·011.

The most eccentric orbit is that of *Æthra* (132), in which ϵ amounts to 0·383.

The least inclined orbit is that of *Massalia* (20), in which ι amounts to 0° 41′.

The most inclined orbit is that of *Pallas* (2), in which ι amounts to 34° 44′.

The brightest, and, presumably, largest planet is by the concurrent testimony of Argelander, Stone, and Pickering, *Vesta* (4) The two former observers place *Ceres* (1) second, and *Pallas* (2) third.

The faintest cannot be specified.

The more recently discovered planets are all so small that it is impossible to say which is the smallest.

It has been thought that many of the minor planets (especially *Vesta*) are variable in their light. This may be nothing more than the result of, and a proof of their axial rotation[e]. Prof.

[d] By far the most elaborate summary which has yet appeared will be found in an article by Niesten in the *Annuaire de l'Observatoire Roy. de Bruxelles*, 1881, p. 226; and see Prof. D. Kirkwood's very exhaustive little treatise *The Asteroids*, Philadelphia, 1888.

[e] Littrow's idea that the planets which exhibit these changes are irregular or polyhedral in form, and show sometimes one and sometimes another face, or faces (as the cases may be), seems sublime fancy. But in the more modern form that probably these planets rotate on their axes as do the major planets, his theory may be admissible.

M. W. Harrington, on the assumption that the surfaces of all have the same reflecting power as *Vesta*, has estimated the volume of *Vesta* as $\frac{5}{17}$ of the first 230 planets; and that *Ceres* and *Vesta* together comprise about half the volume of the 230. Le Verrier calculated that the total mass of the whole number could not exceed $\frac{1}{4}$ of the mass of the Earth. Even to approach this sum total Niesten considers there would have to be several thousand minor planets in all.

Several of the minor planets have been found only to be lost again, and their positions cannot now be determined. Included in this category are *Scylla* (155), *Sylvia* (87), *Diké* (99), and *Camilla* (107). Others (*e.g. Hilda* (153), *Lydia* (110), *Sirona* (116)) have been found again after being lost.

Under favourable circumstances *Ceres* has been seen with the naked eye, having then the brightness of a star of the 7th magnitude; more usually, however, it resembles an 8th magnitude star. Its light is somewhat of a red tinge, and some observers have remarked a haziness surrounding the planet, which has been attributed to the density and extent of its atmosphere. Sir W. Herschel once fancied that he had detected 2 satellites accompanying *Ceres*; but its mass can scarcely be sufficient for it to retain satellites around it large enough to be visible to us. *Pallas*, when nearest the Earth in Opposition, shines as a full 7th magnitude star, with a decided yellowish light. Traces of an atmosphere have also been observed. *Juno* usually shines as an 8th magnitude star, and is of a reddish hue. *Vesta* appears at times as bright as a 6th magnitude star, and may then constantly be seen without optical aid, as was the case in the autumn of 1858. The light of *Vesta* is usually considered to be a pure white, but Hind considers it a pale yellow[f]. Hind found *Victoria* to possess a bluish tinge.

The orbits most nearly alike are those of *Fides* and *Maia*, and Lespiault has remarked that when at their least distance from each other these planets are separated by a space which only

[f] *Sol. Syst.*, p. 85.

amounts to $\frac{1}{20}$ of the radius of the Earth's orbit, or about $4\frac{1}{2}$ millions of miles.

Sir J. Herschel once remarked:—"A man placed on one of the minor planets, would spring with ease 60^{ft}, and sustain in his descent no greater shock than he does on the Earth from leaping a yard. On such planets giants might exist; and those enormous animals which, on Earth, require the buoyant powers of water to counteract their weight, might there be denizens of the land[g]." But to such speculations there is no end.

Respecting the past history, so to speak, of the minor planets, little can be said. Olbers, in calculating the elements of the orbit of *Pallas*, was forcibly struck with the close coincidence he found to exist between the mean distance of that planet and *Ceres*. He then suggested that they might be fragments of some large planet which had, by some catastrophe, been shivered to pieces. When this theory was started it appeared a not wholly improbable one, but the discoveries of late years have upset it[h]. Nevertheless, a very close connection does apparently exist between these minute bodies, and on this subject D'Arrest writes:—"One fact seems above all to confirm the idea of an intimate relation between all the minor planets; it is, that, if their orbits are figured under the form of material rings, these rings will be found so entangled, that it would be possible, by means of one among them taken at hazard, to lift up all the rest."

The circumstances which led originally to a search for planetary bodies in the space intervening between Mars and Jupiter, were these. In the year 1800, 6 astronomers, of whom Baron De

[g] *Outlines of Ast.*, p. 352.

[h] It may be shown mathematically, that if the disruption of a large planet ever did occur, its fragments (no matter how diverse their subsequent paths might be) must, if continuing to revolve round the Sun, always pass through the point at which the explosion occurred, at one part of their orbits. Sir W. Herschel thus expressed himself on this subject to the poet Campbell according to a letter written by the latter:—"He was convinced that there had existed a planet between Mars and Jupiter, in our own system, of which the little asteroids, or planetkins, lately discovered, are indubitably fragments; and 'Remember,' said he, 'that though they have discovered only 4 of these parts, there will be thousands—perhaps 30,000 more yet discovered.' This planet he believed to have been lost by explosion." (*Life and Letters of T. Campbell*, vol. ii. p. 234.)

Zach was one, assembled at Lilienthal, and there resolved to establish a society of 24 practical observers, to examine all the telescopic stars in the zodiac, which was to be divided into 24 zones, each containing one hour of Right Ascension, for the express purpose of searching for undiscovered planets[1]. They elected Schröter their president, and the Baron was chosen their secretary. Such organisation was ere long rewarded by the discovery of 4 planets, but as no more seemed to be forthcoming, the search was relinquished in 1816.

It does not appear that any further labours in this field were prosecuted for some years, or till about the year 1830, when M. Hencke, an amateur of Driesen in Prussia, commenced the search for small planets, with the aid of the since celebrated Berlin Star Maps which contain all stars up to the 9th or 10th magnitudes lying within 15° of the equator. It is evident that a non-stellar body is much more likely to attract the notice of an observer possessing and using maps of this kind than of one not so provided, as a change of position virtually tells its own tale with *comparatively* little trouble to the astronomer. This series of maps, one for each hour of R.A., was only completed in 1859; therefore when Hencke commenced he had only a few at his command, and 15 years elapsed ere his zeal and perseverance produced any result: but when once one planet was found, the discovery of others quickly followed.

Several of these small planets were discovered independently by two or more observers, each without a knowledge of what the other had done. For example, *Irene* was found by Hind on May 19 1851, and by De Gasparis on May 23; *Massilia* by De Gasparis on Sept. 19, 1852, and by Chacornac on Sept. 20; *Amphritrite* by Marth on March 1, 1854, by Pogson on March 2, and Chacornac on March 3 (3 separate discoveries); *Virginia* by Ferguson on Oct. 4, 1857, and by Luther on Oct. 19; *Eurynome* by Watson on Sept. 14, 1863, and by Tempel on Oct. 3; *Hecate* by Watson on July 11, 1868, and by Peters on July 14; *Cassandra* by Peters on July 23, 1871, and by Watson on August 6; &c.

[1] See p. 67, *ante*.

Deducting duplicate discoveries, Palisa carries off the palm for the largest number, for (up to the end of 1888) he had detected 68 minor planets. Then comes Peters with 47; Luther with 23; Watson with 22; Borelly with 15; Goldschmidt with 14; Hind with 10; and so on.

The want of telescopes suitable and *available* for looking after minor planets tends now to hinder new discoveries. All the brighter ones have evidently been found; and, speaking generally, each new one is fainter than its predecessors, and consequently small telescopes are now incapable of doing the work. The following table will show this better than any argument:—

				Mean ☍ Star Mag.
First Group:	Planets	(1) to (10)	... ...	8·5
Second "	"	(11)—(20)	... ...	9·6
Third "	"	(21)—(30)	... ...	10·4
Fourth "	"	(31)—(40)	... ...	11·0
Fifth "	"	(41) (50)	... ...	10·9
Sixth "	"	(51)—(60)	... ...	11·2
Seventh "	"	(61)—(70)	... ...	11·3
Eighth "	"	(71)—(80)	... ...	11·6
Ninth "	"	(81)—(90)	... ...	11·6
Tenth "	"	(91)—(100)	... ...	11·4
Eleventh	"	(101)—(110)	... ...	11·5

The above numbers are not, it is true, in perfect sequence, and it is not possible to complete the Table at present, but my meaning will be sufficiently clear.

The figures in the column headed "Diameter" in the Table (see Book VI, *post*) are the results of calculations by Stone[k]. Photometric experiments made by Professor Stampfer of Vienna yielded somewhat similar results[l]. But both sets of figures are probably more relatively than absolutely accurate. Argelander

[k] *Month. Not.*, vol. xxvii. p. 302. June 1867.

[l] See Bruhns's *De Planetis Minoribus*, Berlin 1856, for details. Some physical investigations by Newcomb into the orbits of certain of these planets will be found in *Mem. of the American Acad.*, vol. v., N.S., pp. 123–35: an abstract appears in *Month. Not.*, vol. xxi. pp. 55–7. Dec. 1860.

published some suggestions for determining the brightness of these planets[m]. Pickering also has made a few endeavours in this direction[n]. In Hornstein's opinion all the larger Minor Planets have now been found, and those having a greater diameter than 25 geographical miles are few in number. Omitting a few of comparatively larger size, he puts the general diameter of the bulk of them at from 5 to 15 miles[o].

Below are given the names of the only minor planets for the determination of whose places we as yet possess Tables. It is not likely that this list will ever be much enlarged, for the increase of late years in the number of these planets has severely taxed the patience of astronomical computers.

By Becker:—Tables for *Amphitrite.*

By Brünnow:—Tables for *Iris*, *Flora*, *Victoria.*

By Hansen:—Tables for *Egeria.*

By Lesser:—Tables for *Metis*, *Lutetia*, *Pomona.*

By Leveau:—Tables for *Vesta.*

By Möller:—Tables for *Pandora.*

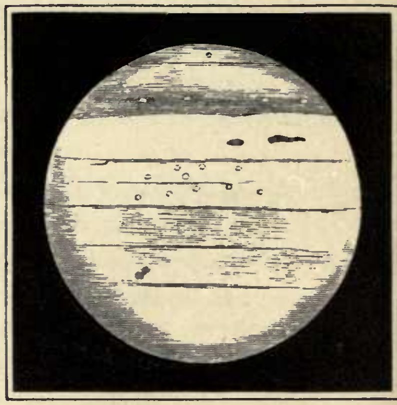
By Schubert:—Tables for *Parthenope*, *Eunomia*, *Melpomene*, *Harmonia.*

[m] *Month. Not.*, vol. xvi. p. 206. June 1856. *Ast. Nach.*, vol. xlii. No. 996. Nov. 29, 1885.

[n] *Annals of the Observatory of Harvard College*, 1879.

[o] *Sitzungsberichte der Math. Naturwissenschaftlichen Classe der Kaiserlichen Akademie*, vol. lxxxiv. pt. ii. p. 7. June 2, 1881.

1857: November 27. (*Dawes.*)



1858: November 18. (*Lassell.*)

1860: March 12. (*Jacob.*)

1860: April 9. (*Baxendell.*)

JUPITER.

CHAPTER XI.

JUPITER[a]. ♃

Period, &c.—Jupiter subject to a slight phase.—Its Belts.—Their physical nature.—First observed by Zucchi.—Dark Spots.—Luminous Spots.—The great Red Spot.—The great White Spot.—Hough's observations.—Alleged Connection between Spots on Jupiter and Spots on the Sun.—Axial rotation of Jupiter.—Centrifugal force at its Equator.—Luminosity of Jupiter.—Its Apparent Motions.—Astrological influences.—Attended by 4 Satellites.—Are they visible to the Naked Eye?—Table of them.—Eclipses of the Satellites.—Occultations.—Transits.—Peculiar aspects of the Satellites when in transit.—Singular circumstance connected with the interior ones.—Instances of all being invisible.—Variations in their brilliancy.—Observations of Eclipses for determining the longitude.—Practical difficulties.—Römer's discovery of the progressive transmission of light.—Mass of Jupiter.—The "Great Inequality."—Tables of Jupiter.

JUPITER, the largest planet of our system, revolves round the Sun in $4332{\cdot}6^{d}$ or $11{\cdot}86^{y}$, at a mean distance of 483,288,000 miles. The eccentricity of its orbit is 0·048, so the planet may recede from the Sun to 506,563,000 miles, or approach it to within 460,013,000 miles. The planet's apparent diameter varies between 49·9″ in opposition and 30·4″ in conjunction, being 40·13″ at its mean distance, according to very elaborate measurements by Main. The equatorial diameter is 88,400 miles or thereabouts. The compression is greater than that of any other planet except Saturn, and amounts, according to the trustworthy observations of Main, to $\frac{1}{16{\cdot}84}$. All the values of this quantity are closely in accord: *e.g.* Lassell gave $\frac{1}{17{\cdot}85}$.

[a] Important modern delineations of Jupiter will be found as follows:—*Month. Not.*, vol. xxxi. p. 34. Dec. 1870 (Browning); vol. xxxiv. p. 235. March 1874 (the Earl of Rosse); vol. xxxiv. p. 403. June 1874 (Knobel).

Jupiter is subject to a slight phase[b]: in quadratures it is gibbous: for reasons referred to in treating of Mars, the illuminated portion always exceeds a semicircle, and in point of fact, owing to the greatly increased distance of Jupiter, the defalcation of light is very small, but perceptible nevertheless in the form of a slight shading off of the limb farthest from the Sun. Webb has noted that this is more easily seen in twilight than in full darkness.

Fig. 85.

JUPITER, OCTOBER 25, 1856. (*De La Rue.*)

The principal telescopic feature of Jupiter—its belts—are well known, at least by name, to every one. They are dusky streaks of varying breadth and number, lying more or less parallel to the planet's equator[c]. Various theories have been broached to explain the belts, but it is generally supposed that the planet is enveloped in dense masses of cloud, and that the belts are merely longitudinal fissures in these clouds, laying bare the

[b] Sir J. Herschel says the contrary, but that is certainly an oversight.

[c] A circumstance first remarked by Grimaldi in 1648.

solid body beneath[d]. The belts, or, as we should on this theory with more propriety call them, the atmospheric fissures, are constantly changing their features: occasionally only 2 or 3 broad ones are seen; at other times as many as 8, 10, or even a dozen narrow ones appear. They are not permanent, but change from time to time, and occasionally with extreme rapidity; even in the course of a few minutes. On this point, writing in 1877, Todd remarks:—"I was much impressed on some nights with the sudden and extensive changes in the cloud belts, as though some tremendous storm was in progress on the planet's surface, changing the form and dimensions of the cloud belts in an hour or two, or even less[e]." At other times the change they undergo is but gradual, and they retain nearly the same forms for several consecutive months. They are commonly absent immediately under the equator, but North and South of this there is usually one wide streak and several narrower ones. At each pole the luminosity of the planet is feebler than elsewhere. The belts, distinguished from the general hue of the planet (often rose-coloured), are usually greyish; but superior optical power brings out traces of a brownish tinge, especially on the larger ones. Occasionally (as, for instance, during the years 1869–72, according to numerous observers) the belts are characterised by much colour; "copper," "deep purple," "claret," "red," "orange," "Roman ochre," are some of the terms employed by Browning and others. A sketch by Lassell is annexed. He described the colours recorded in the margin as "unmistakable[f]." It is also to be remarked that they fade away towards the margin of the disc on either side—a circumstance which it may be presumed is connected with the fact that the portions of the planet's atmosphere near the limbs are necessarily viewed by us obliquely. Sometimes, but rarely, oblique belts may be seen [Figs. 83–4]; and with large telescopes sundry irregularities show themselves, which to smaller instruments are merged in fewer and simpler

[d] I have used the word "clouds" in the text, but their resemblance to the clouds of our own atmosphere must, for many reasons, be only remote.

[e] *Month. Not.*, vol. xxxvii. p. 285, April, 1877.

[f] *Month. Not.*, vol. xxxii. p. 82. Jan. 1872.

outlines. Green has advanced various reasons for the opinion that the bright surface on Jupiter is at a higher elevation than the dark surface, thereby indeed supporting the theory already mentioned[g]. The belts of Jupiter were first observed by Zucchi, at Rome, on May 17, 1630, according to Riccioli[h]; but a claim has been put in on behalf of Torricelli[i].

Fig. 86.

JUPITER, DEC. 30, 1871. (*Lassell.*)

Spots are occasionally, but, with a special exception to be noted presently, not very frequently, visible on Jupiter. Hooke makes the first record of one in May 1664[k]. He watched it in motion for about 2^h, and it seems to have been sheer idleness that led him to neglect observations of it for determining the planet's axial rotation—an honour reserved, as we shall presently see, for J. D. Cassini. Between Dec. 11, 1834 and March 19, 1835, a remarkable spot was observed at Cambridge

[g] *Observatory*, vol. vi. p. 121. April 1883.

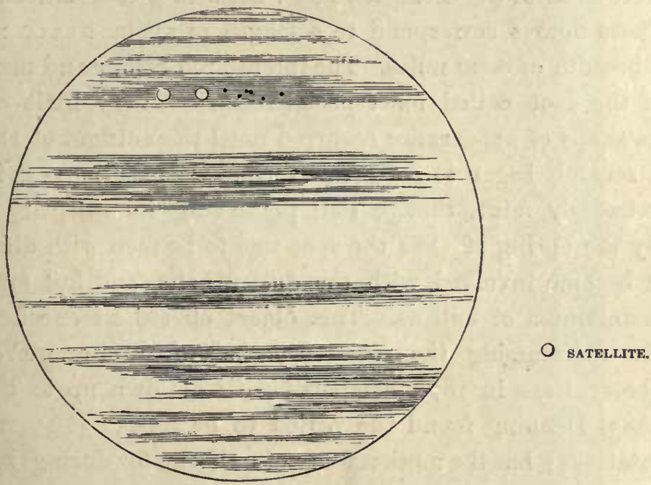
[h] *Almag. Nov.*, vol. i. p. 486.

[i] Moll, *Jour. Royal Inst.*, vol. i. p. 494. May 1831.

[k] *Phil. Trans.*, No. 1.

by Airy: during a portion of this interval a second was seen. In 1843 a very large black spot was observed by Dawes, and in Nov. and Dec. 1858 two oblong dark spots were noted by Lassell as interesting objects [l]. *Luminous* spots closely resembling satellites *in transitu* were detected for the first time in 1849 by Dawes [m], and were seen in the following year by Lassell [n]. In the autumn of 1857 Dawes again noticed some, and forwarded

Fig. 87.



SPOTS ON JUPITER, OCTOBER 6, 1857. (*Sir W. K. Murray.*)

drawings of them to the Royal Astronomical Society, which will repay examination. On Oct. 25 he counted no fewer than 11, all clustered together in the Southern hemisphere [n]. In Nov. of the following year (1858) Lassell observed another cluster, in the Southern hemisphere, but nearer the equator than those seen by Dawes, and in a *bright* belt. [See Pl. XI. Figs. 81–4.] It was much more difficult to catch these than the former ones. Luminous spots were observed also in 1858, 1859, and 1860 by Sir W. K. Murray [o], and in 1870 by various observers.

[l] *Month. Not.* vol. xix. p. 52. Dec. 1858. One of them (in the drawing at least) is precisely like a garden slug!

[m] *Month. Not.*, vol. x. p. 134. April 1850.

[n] *Month. Not.*, vol. xviii. pp. 6 and 49. Nov. and Dec. 1857.

[o] *Month. Not.*, vol. xix. p. 51. Dec. 1858; *Ibid.*, vol. xx. p. 58. Dec. 1859; *Ibid.*, vol. xx. p. 331. June 1860.

The most celebrated spot on Jupiter that has ever been recorded is that which was known as "the great red spot," first conspicuously noticed in July 1878, and which occupied a position immediately South of the dark belt on the Southern boundary of the equator. Its large size and singular boldness of outline aroused the keenest interest amongst astronomers. From measures made with the 18½-in. refractor at Chicago in the years 1879–82, the mean dimensions and position of the spot were as follows:—Length 11·73″, Breadth 3·58″, Latitude 7·25′ S. These figures correspond to a length of about 27,000 miles and a breadth of 8000 miles. The intense red colour and permanency of the spot called for especial remark. Very little change in its shape or appearance occurred until the autumn of 1882, when it sensibly began to fade; and during the ensuing year it became extremely faint, though still preserving its integrity of form. By the spring of 1884 the spot was to be seen with difficulty, as it became involved with the dusky belts, and lost much of its definiteness of outline. This object offered an excellent means for rediscussing the rotation-period of Jupiter. From some observations in 1878, compared with his own up to the end of 1883, Denning found the period to be $9^h\ 55^m\ 36{\cdot}2^s$, from 4586 rotations; but the motion was not uniform, for during the interval of more than 5 years embraced by the observations the time increased 5 seconds. At the Opposition of 1879 it was $9^h\ 55^m\ 34^s$, but in 1883 had increased to $9^h\ 55^m\ 39^s$. This extensive drift in longitude proves the spot to have been atmospheric, and not a fixed object on the actual surface of the planet. The rotation-period it has exhibited may not therefore coincide with the true period of Jupiter.

Fig. 88 represents the red spot on Jupiter as seen with a 10-inch reflector in the summer of 1887.

During the last few years a brilliant white spot has been visible on the equatorial border of the great Southern belt. A curious fact in connection with this spot is, that it moves with a velocity of some 260 miles per hour greater than the red spot. Denning obtained 169 observations of this bright marking during the years 1880–83, and determined the period as $9^h\ 50^m\ 8{\cdot}7^s$ ($5\frac{1}{2}$ minutes less than that of the red spot), and this period increased with the time. In 1880–81 it was $9^h\ 50^m\ 5{\cdot}8^s$, but during 1883 augmented to $9^h\ 50^m\ 11{\cdot}4^s$. The swifter motion of this object enabled it to complete a revolution of Jupiter relatively

Fig. 88.

THE GREAT RED SPOT ON JUPITER, JULY 16, 1887. (*W. F. Denning.*)

to the red spot in $45^d\ 14^h\ 37{\cdot}5^m$. During the 1115 days which elapsed from Nov. 19, 1880, to Dec. 9, 1883, it performed 25 rotations more than the red spot. Although the latter is now somewhat faint, the bright spot gives promise of remaining visible for many years.

During 1886 a large number of observations of Jupiter were made at the Dearborn Observatory, Chicago, U.S., by Prof. G. W. Hough, using the $18\frac{1}{2}$-inch refractor of the observatory. Inasmuch as these observations are not only of high intrinsic interest, but are in conflict to some extent with previous records, a somewhat full abstract of them will be useful [p]:—

"The object of general interest is the great red spot. The outline, shape, and size of this remarkable object has remained without material change from the year 1879, when it was first observed here, until the present time. According to our observations, during the whole of this period it has shown a sharp and well-defined outline, and at no time has it coalesced or been joined to any belt in its proximity, as has been alleged by some observers.

"During the year 1885, the middle of the spot was very much paler in colour than the margins, causing it to appear as an elliptical ring. The ring-form has continued up to the present time. While the outline of the spot has remained very constant, the colour has changed materially from year to year. During the past three years [1884–6] it has at times been very faint, so as barely to be visible.

"The persistence of this object for so many years leads me to infer that the formerly-accepted theory, that the phenomena seen on the surface of the planet are atmospheric, is no longer tenable. The statement so often made in text-books, that in the course of a few days or months the whole aspect of the planet may be changed, is obviously erroneous.

"The rotation-period of Jupiter from the red spot has not materially changed during the past three years. The 'mean' period, 1884–5, was $9^h\ 55^m\ 40.4^s$. Marth's ephemeris for the present year is based on a period of $9^h\ 55^m\ 40.6^s$. The mean correction to this ephemeris is now [May 1887] only about minus 7 minutes, indicating a slightly less value.

"The oval white spots on the Southern hemisphere of the planet, 9″ S. of the equator, have been systematically observed at every Opposition during the past 8 years. They are generally found in groups of three or more, but are rather difficult to observe. The rotation-period deduced from them is nearly the same as from the great red spot.

"These spots usually have a slow drift in longitude of about 0·5° daily in the direction of the planet's rotation, when referred to the great red spot; corresponding to a rotation-period of 20 seconds less than the latter."

It is not known what is the physical nature of either the dark or the luminous spots, but observations by Brett indicate (he thinks) that the large white patches on the equatorial zone of Jupiter *cast shadows*: thus showing that these patches project above the general surface visible to us. The appearances presented point to the conclusion that we do not see the actual body of the planet itself either in the dark belts or in the bright ones [q]. The usual form of both kinds of spots is more or less circular.

It has been already pointed out in Chap. I. (*ante*) that some

[p] *Annual Report of Chicago Ast. Soc.* 1887, p. 10.

[q] *Month. Not.*, vol. xxxiv. p. 359. May 1874.

relationship has been thought to exist between Sun-spots as regards their period and the position of Jupiter in its orbit; but Ranyard extends this idea considerably. He points out an apparent identity in point of time between the prevalence of spots on the Sun and spots on Jupiter, and proceeds to infer that spots on Jupiter are indicative of disturbance on Jupiter, and that both classes of phenomena are dependent upon some extraneous cosmical change, and are in no sense related as cause and effect, the supposed cause being Jupiter's attraction, and the supposed effect an atmospheric tide on the Sun. The observations of Jupiter which are available for the confirmation of the truth of this theory are, previous to 1850, too few and too casual to be conclusive; but such as they are they have been tabulated by Ranyard, and unquestionably countenance his theory[r]. Browning suggests that evidence exists to show that the red colour of Jupiter's belts is a periodical phenomenon coinciding with the epoch of Sun-spot maxima[s]. That in a general way the colour of Jupiter varies from time to time he is firmly convinced.

Cassini, by closely watching the spot which he first saw in July 1665, noticed movement, and regarded this as a proof of the planet's axial rotation, the period of which he found to be about $9^h\ 56^m$. The independent observations of Airy and Mädler in 1835 give $9^h\ 55^m\ 21{\cdot}3^s$, and $9^h\ 55^m\ 26{\cdot}5^s$, and afford another illustration of the care bestowed by Cassini on his astronomical researches. The later observations of Cassini, those of Sir W. Herschel, and those of Schröter indicate results not free from anomalies; Sir William's various determinations fluctuated to an extent of nearly 5^m, a discordance far beyond that which is assignable to errors of observation; and the unavoidable conclusion is, that the spots employed by those 3 astronomers in their investigations were affected (as they themselves believed) by a proper motion of their own. Schmidt found the period to be $9^h\ 55^m\ 28{\cdot}7^s$.

[r] *Month. Not.*, vol. xxxi. p. 34, Dec. 1870; p. 201, May 1871; and p. 224, June 1871.

[s] *Month. Not.*, vol. xxxi. p. 75, Jan. 1871.

The axial rotation of Jupiter being so much quicker than that of the Earth, combined with its diameter being so much greater, results in the rotating velocity of a particle at its equator being greater than on any other planet—466 miles per minute, against the Earth's 17 miles per minute. It will at once be perceived that the intensity of the centrifugal force must be very great, and the polar compression likewise. Hind calls attention to this rapid rotation as offering some compensation, by the heat which it must evolve, for the diminished power of the Sun's rays at the distance of Jupiter.

Under favourable circumstances Jupiter, like Mars, rivals Venus in brilliancy, and even casts a shadow. G. P. Bond found that for photographic purposes its surface reflects light better than that of the Moon in the ratio of 14 to 1 [t]. Zöllner has calculated that Jupiter reflects 0·62 of the light it receives, the Moon reflecting but 0·17 of the incident light. Bond computed that Jupiter actually emits more light than it receives (!): but whether we accept this problematical result, or the more trustworthy one obtained by Zöllner, strong indications of inherent luminosity in Jupiter seem to exist; and this points to the conclusion that this planet is itself a miniature Sun. The heat derived from the Sun only would leave water on Jupiter's surface above 500° below freezing point, so that any *clouds* must arise from internal heat. Moreover, if we conceive the Earth and Jupiter to have been simultaneously created, Jupiter would retain its heat for ages after the Earth had cooled down.

Seen from the Earth the apparent motion of Jupiter is sometimes retrograde. The length of the arc of retrogradation varies from 9° 51′ to 9° 59′, and the time of its performance from 116^d 18^h to 122^d 12^h. The retrograde motion begins or ends, as the case may be, when the planet is at a distance from the Sun, which varies from 113° 35′ to 116° 42′.[u]

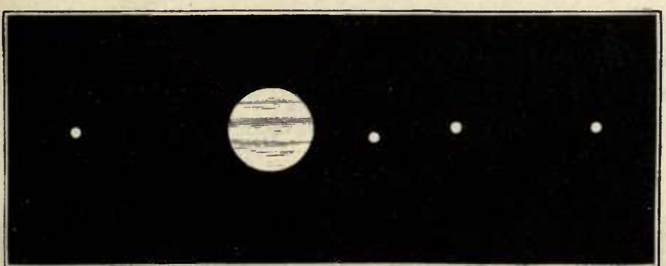
[t] *Month. Not.*, vol. xxi. p. 198. May 1861.

[u] It may here be noted that, as a general rule, the farther a superior planet is from the Sun, the less will be the extent of its arc of retrogression, but the greater will be the time occupied in describing it.

In by-gone days Jupiter was not without its supposed astrological influences. It was considered to be the cause of storms and tempests, and to have power over the prosperity of the vegetable kingdom. Pliny thought that lightning, amongst other things, owed its origin to Jupiter. An old MS. Almanac for 1386 states, that "Jubit es hote and moyste, and doos weel til al thynges, and noyes nothing."

Jupiter is attended by 4 satellites[x], 3 of them seen for the first time by Galileo, at Padua, on January 7, 1610[y], but not determined to be satellites till the following day, whilst the whole four were not seen all together till Jan. 13. They shine with the brilliancy of stars of the 6th or 7th magnitude; but, owing to their proximity to their primary, are usually invisible to the

Fig. 89.



JUPITER AND ITS SATELLITES.

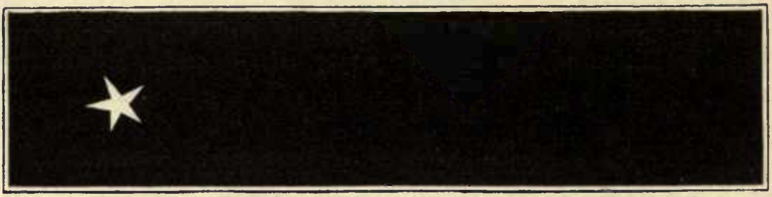
naked eye, though several instances to the contrary are on record. Mr. C. Mason states that on April 15, 1863, finding Jupiter conveniently placed for the purpose, he determined to make a systematic attempt to solve the problem frequently declared to be an impossibility. After a steady gaze of 8^m or 10^m he was able to assure himself that in close proximity to Jupiter he could see a little star. Having resorted to various precautions to prevent self-deception, he at length turned his

[x] Named by Simon Marius, a fraudulent claimant of their discovery, Io, Europa, Ganymede, Callisto. These names have never been in use.

[y] *Siderius Nuncius; Opere di Galileo*, vol. ii. p. 15 *et seq.* Ed. Padua, 1744. An English Translation by E. S. Carlos was published in London in 1880.

refractor of $4\frac{7}{8}$ inches aperture on the planet and found in the position corresponding to that indicated by the naked eye (allowance being made for inversion) all the 4 satellites on the same side of the planet. He states that until referring to the *Nautical Almanac* a few minutes before using the telescope he had no idea

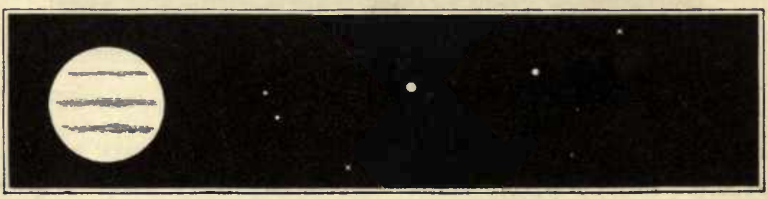
Fig. 90.



JUPITER SEEN WITH THE NAKED EYE, APRIL 15, 1863. (*Mason.*)

as to their configuration, and is the more convinced that with the naked eye he really did see the 4 as *one* [z]. It is quite certain that satellites **II** and **III** were seen on Jan. 15, 1860, by some officers of H. M. S. "*Ajax*," in Kingstown Harbour, near Dublin [a]. Mr. Levander and others at Devizes asserted that on April

Fig. 91.



JUPITER SEEN WITH A TELESCOPE, APRIL 15, 1863. (*Mason.*)

21, 1859, they saw 2 of these bodies. In 1852 an American missionary of the name of Stoddard, at Oroomiah in Persia, repeatedly saw two satellites in the twilight, so long as Jupiter itself was devoid of an overpowering glare. Wrangel, the celebrated Russian traveller, stated that when in Siberia he once met an hunter who said, pointing to Jupiter, "I have just seen that large

[z] *Month. Not.*, vol. xxiii. p. 215. May 1863.

[a] *Month. Not.*, vol. xx. p. 212. March 1860.

THE SATELLITES OF JUPITER.

	Discoverer.	Mean Distance: Radii of ♃	Mean Distance: Miles.	Sidereal Period: d. h. m.	Sidereal Period: d.	Mean Apparent Diam.	Diam.	Diameter seen from ♃'s Equator.	Apparent Diam. of ♃, seen from Satellite.	Max. Elong. ♃ in ☍	Mass ♃ = 1 (Laplace).	Density: ⊕ = 1.	Density: Water = 1.	Appar. Star Mag.
				d. h. m.	d.	″	Miles.	′ ″	° ″	′ ″				
1. Io	Galileo,	6·05	267,300	1 18 29	1·77	1·02	2390	38 11	19 49	2 15	0·000017	0·20	1·12	7
2. Europa ...	Padua,	9·62	425,100	3 13 18	3·55	0·91	2120	17 35	12 25	3 35	0·000023	0·38	2·14	7
3. Ganymede	Jan. 7–13	15·35	678,300	7 4 0	7·17	1·49	3480	18 0	7 47	5 46	0·000088	0·33	1·87	6
4. Callisto ...	1610.	26·99	1,192,800	16 18 5	16·78	1·27	2970	8 46	4 25	9 45	0·000043	0·26	1·47	7

The duration of an eclipse of the Ist is $2^h\ 20^m$
,, ,, IInd 2 56
,, ,, IIIrd 3 43
,, ,, IVth 4 56

—(*Nautical Almanac*, 1835.)

The Eccentricity of the orbits of I and II is = 0: of III and IV is "small and variable."
The Inclination of the orbit of IV is slowly increasing.

star swallow a small one, and vomit it shortly afterwards." The Russian remarks that the sportsman here referred to an immersion and subsequent emersion of the **III**rd satellite, on which Arago, who makes the citation, says, "It is well known that the acuteness of sight of those natives and of the Tartars has become proverbial." Other similar observations, including one by himself, are given by Webb[b], so that we may now regard the question of possibility as decided in the affirmative.

The satellites of Jupiter are capable of being seen with so little optical assistance that it is worth while to enter at some length into a consideration of them.

They are distinguished by ordinal numbers proceding outwards. Thus the "**I**st" satellite is the one nearest to the primary; the "**IV**th" the one most distant therefrom. To determine which is which, the diagrams given in the *Nautical Almanac* will usually be necessary, but the **III**rd, as the largest and brightest, will generally be identified with least difficulty. In small telescopes it is scarcely possible to say that there is anything to distinguish the satellites from stars, beyond a noticeably greater steadiness of light; increased power will reveal discs, but a very considerable augmentation is requisite for detecting physical peculiarities. "The discovery of 4 bodies revolving round a primary, exhibited a beautiful illustration of the Moon's revolution round the Earth, and furnished a most favourable argument in favour of the Copernican theory[c]. The announcement of this fact pointed out also the long vista of similar discoveries which have continued from time to time down to the present day to enrich the solar system, and to shed a lustre on the science of astronomy."

The eclipses, occultations, and transits of the Jovian satellites offer an endless series of interesting, and indeed useful, phenomena. The **I**st, **II**nd, and **III**rd satellites, in consequence of the smallness of the inclinations of their orbits, undergo once in

[b] *Celest. Objects*, p. 144.

[c] The argument, however, failed to command the acceptance of divers Popes and Romish ecclesiastics, who assailed Galileo's views respecting these satellites with great bitterness for many years.

every revolution an eclipse in the shadow cast by the planet into space. The **IV**th, however, frequently escapes this ordeal, in consequence of the plane of its orbit being somewhat more inclined than is the case with the others, and its distance from the primary being so considerable.

When the satellites enter the shadow the *immersion* is said to take place; when they come out of it, the *emersion*—terms which explain themselves. Closely associated with the eclipses are the occultations—a word employed to express the concealment of the satellites by the direct interposition of the planet itself, independently of the shadow. When the planet has passed its conjunction with the Sun, the shadow is projected on the Western side, and at this time both the immersions and emersions of the **III**rd and **IV**th satellites may be observed, but not always those of the **II**nd; and only the emersions of the **I**st, in consequence of its proximity to the planet causing it (after first undergoing an occultation) to enter the shadow behind the planet. When Jupiter is near its Opposition to the Sun, the immersions and emersions take place very close to the planet's limbs. As the planet again approaches Conjunction the shadow is projected on the Eastern side, giving rise to phenomena partly complementary to those set forth above. In other words, whilst the immersions and emersions of **III** and **IV** are always visible, and those of **II** frequently visible, the immersions only of **I** can be perceived because it emerges behind Jupiter; when this one does reappear it is on emersion *from an occultation.*

The occultations "generally require much more powerful instruments for their satisfactory observation than the eclipses. With a telescope of adequate power we may trace the gradual disappearance of the satellite from the first contact with the limb of the planet to its final obscuration behind the disc; and, as viewed with such an instrument, these phenomena are highly interesting. The occultations of the **IV**th satellite are usually visible both at disappearance and at reappearance; those of the **III**rd also are frequently so observable. But it happens much more rarely that the complete phenomenon can be observed in regard to the **II**nd satellite, while the immersion and emersion of the **I**st can only be visible a day or two before or after the Opposition of Jupiter, as at all other times either the immersion or emersion must happen while the satellite is obscured in the planet's shadow. Thus it most usually occurs that from Conjunction to Opposition the *reappearances* only of the **I**st and **II**nd satellite can be observed, and the *disappearances* only from Opposition to Conjunction[d]."

Far more interesting are the transits of the satellites and their shadows across the planet—phenomena which, it is easy to understand, are of frequent occurrence when the satellites are in those parts of their respective orbits which lie nearest to the Earth. The satellites appear on the disc of their primary as round luminous spots preceded or followed by their shadows, which show themselves as round black or blackish[e] spots. The shadow precedes the satellite when Jupiter is passing from Conjunction to Opposition, but follows it when the primary is between Opposition and Conjunction. When actually in Conjunction the shadow is in a right line with the satellite, and the two may be superposed.

Some peculiarities in the appearance of the satellites during transit are too well attested to be passed over. **III** in particular is nearly always seen almost or quite as dark as its shadow, but on rare occasions appears dusky and shaded. **IV** has been often seen dark[f], but, according to Dawes, **II** has never had the slightest shading on the disc within his knowledge, and **I** only a grey tinge, inferior by many shades to that usually possessed by **III**. Contrast has evidently a good deal to do with the bringing out of these shadings, but the circumstances attending

[d] Hind, *Sol. Syst.*, p. 100. (Modified in one place.)

[e] *Blackish*, because the visible margin is not that of the true shadow, but of a penumbra which surrounds the shadow, though it is rare for this penumbra to be observable as an actual ring surrounding the shadow. (See an instance recorded by T. H. Buffham in *Ast. Reg.*, vol. viii. p. 37. Feb. 1870.)

[f] Roberts (*Month. Not.*, vol. xxxiii. p. 412. April 1873); Firmstone (*Ibid.*, p. 460. May 1873); Burton (*Ibid.*, p. 472. Jnne 1873), &c. On Aug. 21, 1867, Prince saw IV as a "round black spot," its colour being as nearly as possible that of its own shadow" (*Month. Not.*, vol. xxvii p. 318).

the recorded variations in this intensity are less intelligible. J. D. Cassini, Maraldi, Pound[g], Messier[h], Schröter, and Sir W. Herschel were amongst the earlier observers of these peculiarities, and W. C. Bond, Lassell, and Dawes amongst the more modern ones. Bond saw **III** as a well-defined black spot on Jan. 28, 1848, and again on March 11. He stated that, on March 18, it entered upon the disc as a very bright spot, more brilliant than the surrounding surface; that 20^m later it had so decreased in brightness as to be hardly perceptible, and that in another few minutes a dark spot suddenly appeared in its place, which was seen for 2$\frac{1}{2}^h$. This spot was sufficiently conspicuous to be measured with a micrometer, was

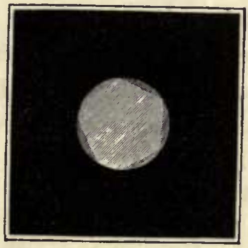
Fig. 92.

THE IV[th] SATELLITE OF JUPITER, MARCH 26, 1873. (*G. W. Roberts.*)

Fig. 93.

THE III[rd] SATELLITE OF JUPITER, JAN. 31, 1860. (*Dawes.*)

Fig. 94.



THE IV[th] SATELLITE OF JUPITER, FEB. 12, 1849. *Dawes.*

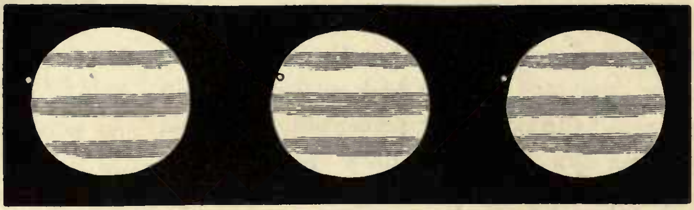
perfectly black, nearly round. and *on* the satellite. The converse of this—the satellite dark first and bright afterwards—was witnessed by Prince and Brodie on Jan. 31, 1860[i].

On June 26, 1828, **II**, having entered on the disc of Jupiter, was seen 12^m or 13^m afterwards *outside* the limb, where it remained visible for at least 4^m and then suddenly vanished. Three observers of eminence (Sir T. Maclear, Adm. Smyth, and Dr. Pearson) record this, so there can scarcely have been any

[g] *Phil. Trans.*, vol. xxx. p. 900.
[h] *Phil. Trans.*, vol. lix. p. 459. 1769.
[i] *Month. Not.*, vol. xx. p. 212. March 1860.

individual optical illusion, much less deception. It has been suggested that an eclipse of the satellite by another satellite would meet the facts of the case, provided we could establish a doubt as to whether these observers for a certainty saw the satellite previously *on* the disc of the planet.

Fig. 95.



JUPITER WITH SATELLITE IN TRANSIT, JUNE 26, 1828. (*Smyth.*)

Lassell has found the shadow of **IV** very much larger than the satellite itself, even to the amount of double the diameter, and the same shadow larger than that of **III**, though the satellite itself is smaller than **III**. The shadow of **II** has been seen, it is said, to possess an irregular outline, but the observation is not well attested.

On April 5, 1861, Mr. T. Barneby saw the shadow of **III** first in the shape of a broad dark streak such as the cone of the shadow would represent in a slanting direction, but it shortly afterwards appeared as a circular spot perfectly dark and much *larger* than the shadow (which was visible at the same time) of **I**. I cite this passage chiefly because of the information about the form of the projection of the shadow, which, though very reasonable and obvious, is noticeable as the only instance I have met with.

On April 17, 1861, the Rev. R. Main saw **II** occulted by **I**, and the two appeared as one for some 7^m or 8^m.

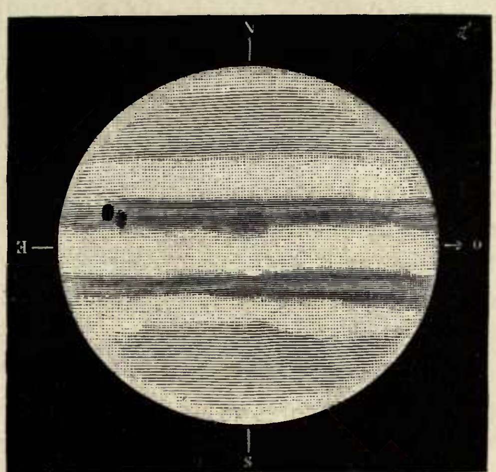
On Jan. 14, 1872, Mr. F. M. Newton saw **I** superposed on its shadow, so that the satellite appeared to be surrounded by a dark ring. This observation seems to be unique[k]. The nearest

[k] Letter in *Eng. Mech.*, vol. xxiii. p. 562. Aug. 11, 1876.

approach to it is an observation by Mr. G. D. Hirst, on May 13, 1876, of **I** in transit partly occulting its own shadow, so that the shadow appeared as a narrow black *crescent*. The satellite itself was not seen except when near the edge of the planet's disc[1].

Fig 96 represents a singular observation made by Trouvelot at Cambridge, U.S., on April 24, 1887.

Fig. 96.



JUPITER'S 1ST SATELLITE IN TRANSIT, WITH A DOUBLE SHADOW, APRIL 24, 1877. (*Trouvelot.*)

"The shadow of the first satellite which had entered on Jupiter 39 minutes previously had not yet quite gone a quarter of its way across the disc. This shadow, black and of a sensibly elliptical form, doubtless on account of the fact that it was seen projected not far from the edge of a spherical surface, almost touched at its most northern point the northern edge of the pink equatorial zone. It was preceded on its western side by a rather dark spot, which was of exactly the same shape and size, and only separated from the shadow by a space equal at

[1] Letter in *Eng. Mech.*, vol. xiv. p. 535. Feb. 9, 1872.

the most to one-third of the equatorial diameter of the shadow. This remarkable spot was not exactly on the same horizontal line as the shadow of satellite **I**, but lay about one third of the vertical diameter of the shadow towards the South."

Trouvelot goes on to say that he watched the phenomenon for altogether $1^h\ 20^m$, or until the primary shadow had accomplished about $\frac{3}{4}$ of its journey across the planet, when it ceased. He assured himself that it was neither a planetary spot, properly so called, nor a satellite that he had seen, and he regarded it as simply a secondary shadow—a shadow of the main shadow seen projected on a lower stratum of Jupiter's atmosphere (or even it might be on the solid body of the planet), which would account also for the secondary shadow being much less intense than the primary or ordinary one[m].

As to certain irregularities of figures presented by **IV** when seen as a dark spot on the disc of Jupiter, reference may be made to a paper by Burton[n].

The phenomena exhibited by the satellites in transit have been carefully studied by Spitta, and his conclusions in a summary form will be useful for reference:—**IV** is fainter than the others on approaching the limb of the planet; bright for first 10 or 15 minutes of transit; lost for about the same time; reappears as a dark spot, becoming jet black: **II** always bright during transit; brilliancy least affected on approaching limb: **III** sometimes becomes lost, reappearing as a dark spot; at others, remains white throughout: **I** after becoming lost, usually turns one of the shades of grey to nearly black[o].

Jupiter's satellites move in orbits nearly circular, and between the motions of the first three a singular relation exists:—*The mean sidereal motion of* **I** *added to twice that of* **III**, *is constantly equal to three times that of* **II**; *so that the sidereal longitude of* **I**, *plus twice that of* **III**, *minus three times that of* **II**, *yields a remainder always constant, and in fact equal to* 180°. This relation

[m] *L'Astronomie*, vol. vi. p. 414. Nov. 1887.

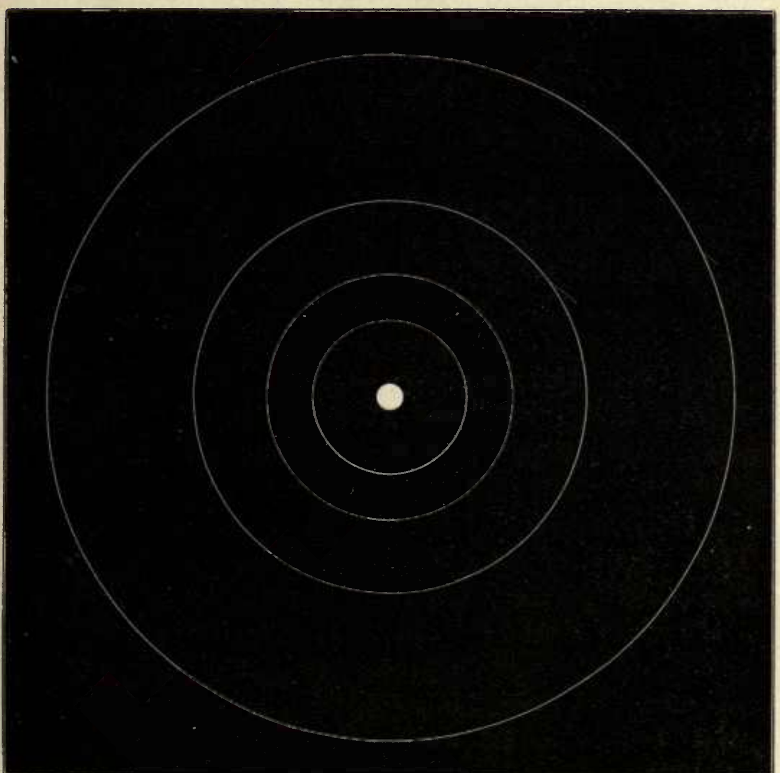
[n] *Month. Not*, vol xxxiii. p. 472. June 1873.

[o] *Month. Not.*, vol. xlviii. p. 34. Nov. 1887.

will be better understood by an inspection of the following table:—

	Sidereal motion per second of time.			
Satellite **I.**	8·478706 × 1	=	8·478706.	(*a*)
„ **II.**	4·223947 × 3	=	12·671841.	(*b*)
„ **III.**	2·096567 × 2	=	4·193134.	(*c*)

Fig. 97.



PLAN OF THE JOVIAN SYSTEM [p].

[p] The satellite orbits in this and the following chapters are all drawn to the same scale. No diagram on a plane on the same scale of the orbits of the satellites of Mars is given in this volume, because on the scale here employed, those orbits would be of microscopic dimensions.

Adding together *a* and *c*, we get 12·671840, which quantity is to 5 places of decimals the same as *b*. From this it follows that for an enormous period of time the 3 interior satellites cannot all be eclipsed at the same time; for in the simultaneous eclipses of **II** and **III**, **I** will always be in conjunction with Jupiter, and so on[q]. Making use of his own tables, Wargentin has calculated that simultaneous eclipses of the 3 satellites cannot take place before the lapse of 1,317,900 years[r], and an alteration of only 0·33″ in the annual motion of **II** would suffice to render the phenomenon for ever impossible.

D'Arrest pointed out the commensurability, within a few hours, of 5187 revolutions of **I**, 2583 of **II**, 1281 of **III**, and 548 of **IV**, in $25^y\ 55^d$, when the same geometric configuration will recur.

The exact figures are given by him[s] as follow :—

	Revolutions.		Days
Satellite **I**.	5187	=	9180·27.
„ **II**.	2583	=	9180·23.
„ **III**.	1281	=	9180·14.
„ **IV**.	548	=	9180·95.

Between satellites **III** and **IV** the following comparatively coarse approximation subsists. *Seven* times the period of the former ($50^d\ 1^h\ 57^m\ 53^s{\cdot}520$) exceeds by only $21^m\ 19^s{\cdot}7$ *three* times the period of the latter ($50^d\ 1^h\ 36^m\ 33^s{\cdot}813$). Moreover the periods of **I**, **II**, and **III** stand in the ratio of 1, 2 and 4, as near as may be.

The following special elements are given by Hind[t]. "The line of apsides of the **III**rd satellite revolves in about 137^y, and that of the **IV**th in about 516^y. The lines of nodes of the 3 exterior satellites revolve in a *retrogade* direction, as is the case with the nodes of the lunar orbit; the period for the **II**nd is 30^y, for the **III**rd 140^y, and for the **IV**th 520^y."

It occasionally, but very rarely, happens that all 4 satellites are for a short time invisible, being either directly in front of, or

[q] Laplace demonstrated by the theory of Gravitation that if this relation be once approximately begun, it will *always* last.

[r] *Acta Soc. Upsal.*, p. 41. 1743.

[s] *Ast. Nach.*, vol. lviii. No. 1377. Aug. 25, 1862.

[t] *Sol. Syst.*, p. 98.

behind, the planet. Such was the case, according to Molyneux[u], on Nov. 2, 1681 (O. S.) The same thing was noticed by Sir W. Herschel on May 23, 1802; by Wallis on April 15, 1826; by Dawes and W. Griesbach on Sept. 27, 1843. Dawes published in 1862 an account of his observations[w]. Jupiter's (apparent) deprivation of its satellites lasted about 35^m. A repetition of this phenomenon occurred on Aug. 21, 1867, when the planet was for $1\frac{3}{4}^h$ apparently without satellites projected on the sky.

The satellites appear to vary in brilliancy in a way wholly inexplicable. I have already stated that **III** is commonly the *brightest*; but Maraldi and Bond have seen the contrary. On the whole, perhaps, we are justified in saying that the *faintest* is **IV**; but the lustre of this is irregular: in 1711 Bianchini and another, and on June 13, 1849, Lassell, saw it so feeble as to be almost invisible, whilst Webb repeatedly saw it surpass **III**. This observer wrote—"Spots . . . may easily cause this variable light; but a stranger anomaly has been perceived,—the discs themselves do not always appear of the same size or form. W. Herschel noticed the former fact, and inferred the latter; and both have been since confirmed by others. Beer and Mädler, Lassell, Secchi and Buffham have sometimes seen the disc of **II** larger than **I**; and Lassell, and Secchi and his assistant, and Burton have distinctly seen that of **III** irregular and elliptical; and according to the Roman observers the ellipse does not always lie the same way: Mitchell also, with an 11-inch achromatic, has observed this disc irregular and hazy. Buffham has often found **IV** the smallest of all, and irregular-looking. Phenomena so minute hardly find a suitable place in these pages, but they seem too singular to be omitted; and in some cases, possibly small instruments [?] may indicate them; at least, with an inferior fluid achromatic reduced to 3 inches aperture I have sometimes noticed differences in the size of the discs which I thought were not imaginary[x]."

Sir W. Herschel, by attentive and prolonged observation, was

[u] *Opticks*, p. 271.
[w] *Month. Not.*, vol. xxii. p. 292. June 1862.
[x] *Celest. Objects*, 4th ed., p. 162.

led to infer that each of the satellites rotated on its axis in the same time that it made a sidereal revolution round its primary thus presenting an analogy to the case of our Moon. The immediate reason which led to this conclusion was a belief that the variation in their brilliancy always recurred in nearly the same positions of the satellites with respect to Jupiter and the Sun, which supposition had previously presented itself to the mind of Cassini[y]. But modern observations do not harmonise with these statements; that is to say, we are not entitled to affirm now that peculiarities in the appearances of the satellites correspond with definite orbital positions. On the contrary, the peculiarities observed are not governed by any known law of time or place.

Arago thus summed up Sir W. Herschel's photometric deductions. "The **I**st satellite is at its maximum brightness when it attains the point of its orbit which is almost midway between the greatest Eastern Elongation and its Conjunction. The brightest side of the **II**nd satellite is also turned towards the Earth when that body is between the greatest Eastern Elongation and Conjunction. The brightness of the **III**rd satellite attains 2 maxima in the course of a revolution, namely at the 2 Elongations. The **IV**th shines with a bright light only a little before and a little after Opposition[z]."

Various observers have assigned colours, or rather tinges of colour, to the different satellites, but the results are not sufficiently of accord to be worth citing.

Eclipses as viewed *on* Jupiter take place on a grand scale; for in consequence of the small inclinations of the orbits of the satellites to the planet's equator and the small inclination of the latter to the ecliptic, all the satellites, the **IV**th excepted, are eclipsed some time in every revolution; so that a spectator on Jupiter might witness during the Jovian year 4500 eclipses of the Moon (Moons) and about the same number of the Sun.

Soon after their discovery it suggested itself to the reflecting

[y] *Mém. Acad. des Sciences*, vol. i. p. 266.

[z] *Pop. Ast.*, vol. ii. p. 549. Eng. ed.

mind of Galileo that eclipses of the satellites of Jupiter might be made useful for determining the longitude. Regarding eclipses as instantaneous phenomena visible at the same moment in every place which has the planet above its horizon, it is clear that a comparison of observations recorded in 2 local times would afford data for determining the difference of time (longitude) between the places to which the times belong. Eclipses accurately *predicted* for one meridian when observed under another one would afford a still more advanced means of ascertaining the difference of longitude between them. These eclipses could be predicted if sufficiently accurate tables of the satellites were in existence; but at sea, where the problem has chiefly to be solved, they cannot be observed with the most refined accuracy, and on land some difficulties present themselves; so that the method to some extent breaks down, and is only available where very rough approximations will suffice.

It was to observations of one of the satellites of Jupiter, and Römer's discussion of them in 1675, that we owe the discovery that light is not propagated instantaneously through space[a]. It was found that the calculated times of the eclipses did not correspond with the observed times, and that the difference was a quantity constantly affected by opposite signs of error according as Jupiter was in perigee or apogee. In the former case the eclipse always occurred before the calculated time; in the latter, always after it. The regularity with which these anomalies showed themselves led Römer to suspect that they had their origin in the variations which occurred in the distance of Jupiter from the Earth: that as this distance increased or diminished so a longer or a shorter period was requisite for light to traverse the space between the 2 planets. Assuming from the data in his possession that light travelled at the rate of 192,000 miles per second, and required $16\frac{1}{2}^m$ to traverse the diameter of the Earth's orbit, and applying this (as yet hypothetical) conclusion to the eclipses in the form of a trial-correction, Römer promptly obtained proofs of the accuracy of his reasoning; but it was Bradley's discovery

[a] *Opere di Galileo*, vol. ii. p. 33. Padua ed., 1744.

of aberration some half a century later which completely demonstrated the soundness of Römcr's views and caused their general acceptance. The modern experiments of Fizeau have given for the velocity of light a result but slightly differing in amount from Römer's, namely, 194,000 miles per second[b].

Like most new discoveries Römer's did not, when promulgated, find favour in the scientific world, and many years elapsed ere it was generally accepted.

The mass of Jupiter has never been a very doubtful quantity, all the values of it being much more in accord with one another than is usually the case. Laplace, from Pound's observations of the **IV**[th] satellite, placed it at $\frac{1}{1067}$; Bouvard, from the perturbations of Saturn, at $\frac{1}{1070}$; Nicolai, from the perturbations of Juno, at $\frac{1}{1053\cdot92}$; Encke, from the perturbations of Vesta, at $\frac{1}{1050}$; and from perturbations of the Comet bearing his name, at $\frac{1}{1054}$; Santini at $\frac{1}{1050}$; Bessel at $\frac{1}{1047\cdot87}$; Airy, from motions of the satellites, at $\frac{1}{1046\cdot77}$; Krüger, from observations of Themis, at $\frac{1}{1047\cdot54}$; Jacob, from the motions of the satellites, at $\frac{1}{1047\cdot54}$; and Möller, from the motions of Faye's Comet, at $\frac{1}{1047\cdot78}$; Schur, from heliometer measures of the satellites, at $\frac{1}{1047\cdot23}$. Any one of the 4 last values may be taken to be substantially exact.

"The most ancient observation of Jupiter which we are acquainted with is that reported by Ptolemy in Book X. chap. iii. of the *Almagest*, and considered by him free from all doubt. It is dated in the 83rd year after the death of Alexander the Great, on the 18th of the Egyptian month *Epiphi*, in the morning, when the planet eclipsed the star now known as δ Cancri. This observation was made on Sept. 3, B.C. 240, about 18^h on the meridian of Alexandria."

This is a convenient place to mention the "Great Inequality" in the motion of Jupiter and Saturn, so far as the fact of its

[b] In consequence of the increase in the received value of the Sun's parallax a reduction in the velocity of light by several thousands of miles per second must be assumed, and singularly enough some experiments of Foucault's *made before the parallax question came up for general discussion* pointed to the same conclusion. The value for the velocity of light now generally accepted is about 186,660 miles per second.

existence is concerned, for a particular account of it would be altogether foreign to the purposes of this work [c]. The period of each of these planets is subject to a continuous change owing to the mutual influence exerted by each on the orbit of the other and the time required for this change to go through its various stages is the Period of the Great Inequality. It amounts to 918 years.

The Tables of Jupiter used till recently were those of A. Bouvard, published in 1821, but the new and far superior Tables of Le Verrier have superseded them [d]. For the satellites, Damoiseau's Tables (published in 1836) are employed. As regards the satellites there is room for much improvement in the Tables at present employed. They fail to give results characterised by the precision which modern science demands.

[c] See Sir J. Herschel's *Outlines*, p. 502.

[d] These tables were employed for the first time in England in the preparation of the *Nautical Almanac* for 1878.

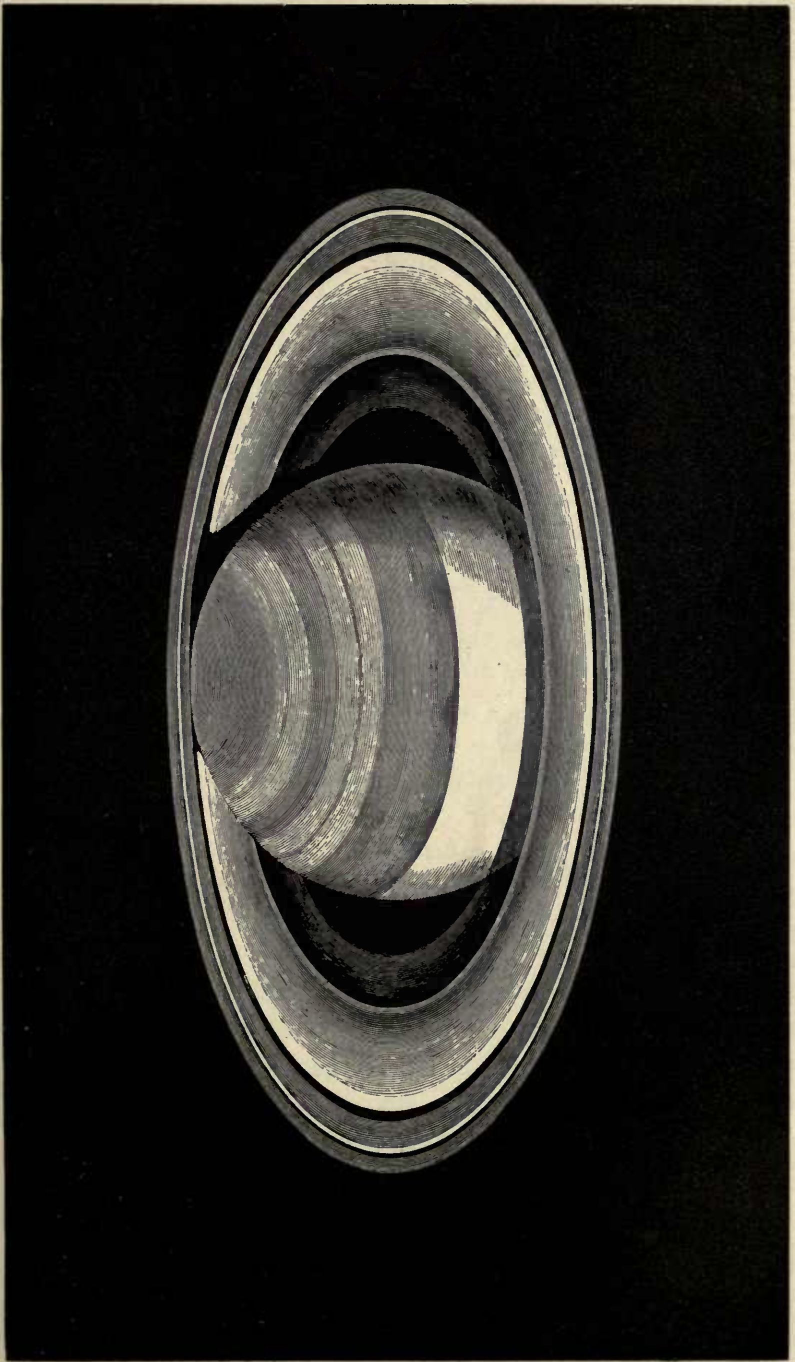
CHAPTER XII.

SATURN[a]. ♄

Period, &c.—Figure and Colour of Saturn.—Belts and Spots.—Observations of the Belts by Holden.—By Ranyard.—Bright spot recorded by Hall.—Probable atmosphere.—Observations of Galileo, and the perplexity they caused.—Logogriph sent by him to Kepler.—Huygens's discovery of the Ring.—His logogriph.—The bisection of the Ring discovered by the brothers Ball.—Sir W. Herschel's Doubts.—Historical epitome of the progress of discovery.—The "Dusky" Ring.—Facts relating to the Rings.—Appearances presented by them under different circumstances.—Rotation of the Ring.—Secchi's inquiries into this.—The Ring not concentric with the Ball.—Measurements by W. Struve.—Other measurements.—Miscellaneous particulars.—Theory of the Ring being fluid.—Now thought to consist of an aggregation of Satellites.—The "Beaded" appearance of the Ring.—O. Struve's surmise about its contraction.—Irregularities in the appearances of the ansæ.—Rings not bounded by plane surfaces.—Mountains suspected on them.—An atmosphere suspected.—Physical observations between 1872 *and* 1876 *by Trouvelot.—Observations by MM. Henry.—By Keeler.—Brightness of Rings and Ball.—Bessel's investigations into the Mass of the Rings.—Saturn attended by* 8 *Satellites.—Table of them.—Physical data relating to each.—Elements by Jacob.—Coincidences in the Rotation-periods of certain of them.—Transits of Titan.—Celestial phenomena on Saturn.—Lockyer's summary of the appearances presented by the Rings.—Peculiarity relative to the illumination of Iapetus.—Mass of Saturn.—Ancient observations.—Saturnian Astronomy.*

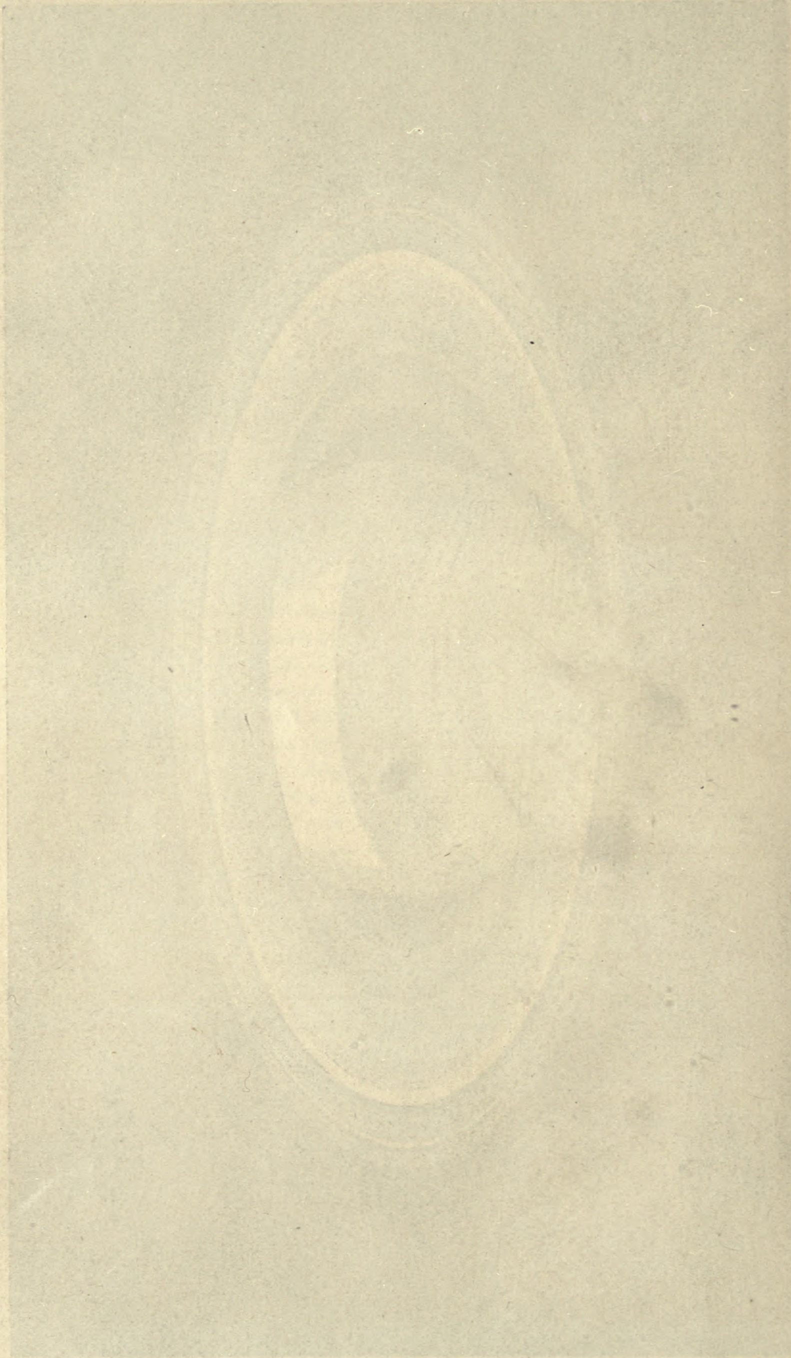
INFERIOR in size to Jupiter only, Saturn may fairly be pronounced to be the most interesting member of the Solar System. It revolves round the Sun in 10759·2^d or 29·45^y at a

[a] For drawings, &c. of Saturn, see *Annals of Harvard Coll. Obs.*, vol. ii. (120 drawings by the Bonds); *Ast. Nach.*, vol. xxviii. No. 650, Nov. 1848 (J. F. J. Schmidt); *Ibid.*, vol. xxxix. No. 929, Jan. 8, 1855 (Secchi); *Mem. R.A.S.*, vol. iv. p. 383 (Kater); *Ibid.*, vol. xxi. p. 151 (8 figs. by Lassell); *Month. Not.*, vol. xi. p. 23 (Dawes and Lassell); *Ibid.*, vol. xiii. p. 16 (Dawes); *Ibid.*, vol. xiv. p. 17 (Dawes); *Ibid.*, xv. p. 79 (Dawes); *Ibid.*, vol. xvi. p. 120 (one fig. by Jacob); *Ibid.*, vol. xviii. p. 75 (abstract of *Harvard Obs.*); and vol. xxii. p. 89 (two figs. by Jacob); *Student*, vol. ii. p. 240 (Browning). *Month. Not.*, vol. xliv. p. 407 (Pratt); *Ibid.*, vol. xlv. p. 401 (Green); *Ast. Nach.*, vol. cxii. No. 2682 (Lamp); *Month. Not.*, vol. xlvii. p. 514 (Elger); *L'Astronomie*, vol. vi. p. 208 (Stuyvaert).



SATURN. March 27 and 29, 1856. (*De La Rue.*)

*** The dark ring C is very decidedly *too narrow* as indicated in the engraving.



mean distance of 886,065,000 miles, which an orbital eccentricity of 0·056 may increase to 931,033,000 or diminish to 841,097,000 miles. Its apparent diameter varies between 15·1″ in conjunction, and 20·7″ in opposition, and its real (equatorial) diameter may be taken at 75,036 miles. Its polar compression is larger than that of any other planet, Jupiter not excepted: but it is usually less noticeable than that of Jupiter because the ring distracts the eye. Sir W. Herschel's value of the compression is $\frac{1}{10\cdot34}$; Bessel's $\frac{1}{10\cdot19}$; the Rev. R. Main's $\frac{1}{9\cdot22}$ [b]; and Hind's $\frac{1}{9\cdot02}$.

Saturn has no *perceptible* phases. The maximum defalcation of light under extreme circumstances is so small that the maximum breadth of the shaded area can hardly be $\frac{1}{20}$ of a second of arc —a quantity inappreciable.

The figure of Saturn is now quite understood to be that of an oblate spheroid, but at one time considerable doubt existed about the matter in consequence of Sir W. Herschel having advanced the opinion, from observations made in April 1805, that the planet was compressed at the equator as well as at the poles; or, as it is generally phrased, that it resembles a parallelogram with the corners rounded off, so as to leave both the equatorial and the polar regions flatter than they would be in a regular spheroidal figure. This opinion, never received with much favour (though *not* entirely unconfirmed by later observers), is now almost universally repudiated, chiefly owing to the micrometrical measurements performed by Bessel in 1833 and by Main in 1848. Some optical illusion was probably at the foundation of it, though it is right to say that the notion is believed in to this day by some persons, and ascribed to an actual upheaval of the planet's surface recurring from time to time and due to quasi-volcanic causes. It must also be added, that (as in the case of Jupiter) we only see the outline of Saturn's *atmosphere* and not that of the solid (or fluid) body of the planet itself.

Belts exist on Saturn resembling those of Jupiter, but they

[b] See *Month. Not.*, vol. xiii. p. 79, Jan. 1853, for others, and same vol., p. 152, for a note by the Rev. R. Main: an important memoir by the same observer appears in *Mem. R.A.S.*, vol. xviii. p. 27, 1850.

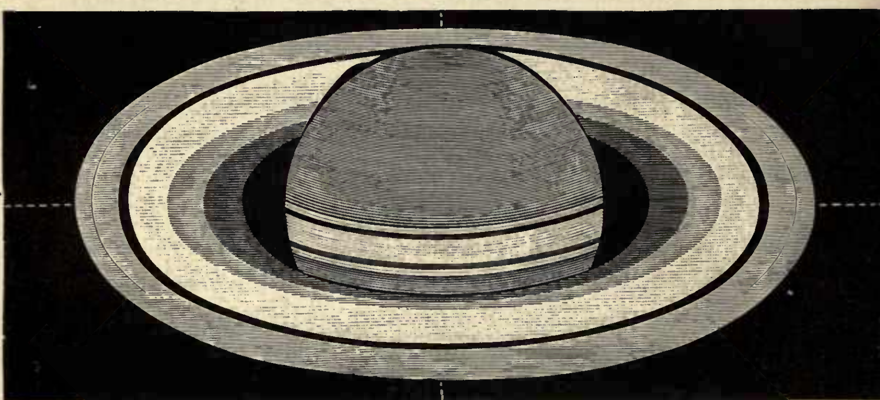
are very much fainter. They are probably of the same physical character.

In November and December 1883 several observers noticed a singular configuration of dark and bright belts on Saturn, the character of which will be best understood by a careful perusal of the following description by Professor E. S. Holden. Under date Dec. 2 he writes :—" The S. pole is mottled, especially so near of the shadows. The bright equatorial belt is bounded on the S. by a narrow dark streak some 2″ wide; it is the darkest thing on the ball.

Fig. 99.

S

W



N

Saturn, Dec. 2, 1883. (*Holden.*)

S. of this is an equally narrow bright streak, then S. of this is the nearly uniform S. hemisphere. N. of the equatorial bright belt is a narrow dusky belt (1″·5 ?), then a narrow bright belt (1″·5 ?), and then a dark band, which is the dusky ring itself (ring **C**). The principal division is seen all around; the division in ring **A** is seen at both ends. The shadow of the ball on the ring is as drawn. It is wider and of a different shape on the preceding side, as drawn. I did not specially look for (nor see) the shadow of the ball on the ring **C** " [this being a test of good images].

Fig. 114 (p. 224) gives a view of an isolated narrow belt, stretching right across the ball, seen by Ranyard on Nov. 4, 1883, and subsequently.

It was Lassell's opinion that, taking the planet as a whole, it may be said that the South pole is generally darker than the North pole and more blue in tinge. The dark belts on the planet are often thought to exhibit a greenish hue. The planet's ordinary colour is yellowish white, the belts inclining to grayish white. Browning finds that large apertures bring out the existence of considerable diversities of colour on Saturn. Any first-class telescope of 4 inches aperture will exhibit the marked distinction between the yellow tint of Saturn's globe and the silvery or bluish white hue of ring **B**.

The belts of Saturn differ from those of Jupiter in the respect that they exhibit at times a sensible curvature, whilst those of Jupiter are rectilinear. Hence we draw the conclusion that if the belts of Saturn are parallel to the planet's equator (as probably is the case), then the plane of this equator must make a rather considerable angle with the ecliptic. A quintuple belt furnished Sir W. Herschel with the means of determining the period of the planet's axial rotation, which he fixed at $10^h\ 16^m\ 0{\cdot}44^s$, from observations extending over 100 rotations between Dec. 4, 1793 and Jan. 16, 1794[c]. He is said to have subsequently made the period to be $10^h\ 29^m\ 16{\cdot}8^s$. Schröter's results exceed this, but contradict one another considerably. His highest result was as much as 12^h.

Spots on Saturn are very rare. The instances on record hardly number a dozen. On Dec. 7, 1876 A. Hall at Washington observed a bright spot 2″ or 3″ in diameter, round, and well defined, and brilliantly white. It lasted nearly a month, and was seen by several observers[d]. It yielded for the period of Saturn's rotation $10^h\ 14^m\ 23{\cdot}8^s$.

Sir W. Herschel considered that he had obtained decided indications of the existence of an atmosphere on Saturn: the satellites when undergoing occultation never disappeared instantaneously, but seemed to hang on the planet's limb, in one case for as long as 20^m. Such a retardation would imply a horizontal

[c] *Phil. Trans.*, vol. lxxxiv. p. 62. 1794.

[d] *Ast. Nach.*, vol. xc. No. 2146, Aug. 16, 1877.

refraction of 2″, but no confirmation of this has been obtained by any subsequent observer. The same observer found other proofs of an atmosphere: an examination of the polar regions on various occasions shewed that according as they were turned towards or from the Sun a difference of hue was perceptible, which might reasonably be supposed to be duc to snow in those regions melting under the Sun's rays, and accumulating in the absence of those rays, as has been explained when speaking of Mars.

When Saturn was first telescopically examined by Galileo, he noticed that it presented a very oval outline, which in his opinion gave the notion of a large planet having on each side of it one smaller one. He added, that with telescopes of superior power, the planet did not appear triple, but exhibited an oblong form, somewhat like the shape of an olive[e].

Continuing his observations, the illustrious astronomer was not long in noticing that the two (supposed) bodies gradually decreased in size, though still in the same position as regards their primary[f], until they finally disappeared altogether[g]. Galileo's amazement at this was unbounded, and his third letter to Welser, dated Dec. 4, 1612, in which he expresses his feelings on the subject, is still extant. He remarks:—

"What is to be said concerning so strange a metamorphosis? Are the two lesser stars consumed after the manner of the solar spots? Have they vanished or suddenly fled? Has Saturn, perhaps, devoured his own children? Or were the appearances indeed illusion or fraud, with which the glasses have so long deceived me, as well as many others to whom I have shewn them? Now, perhaps, is the time come to revive the well-nigh withered hopes of those who, guided by more profound contemplations, have discovered the fallacy of the new observations, and demonstrated the utter impossibility of their existence. I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature

[e] *Opere di Galileo*, vol. ii. p. 41. Padua ed., 1744.

[f] *Ibid.*

[g] A nodal passage took place in Dec. 1612, when of course Saturn would in such a telescope as Galileo's appear to be destitute of all appendages whatever.

of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me[h]." Galileo was so disgusted that he entirely abandoned observations of Saturn.

The original discovery was announced to Kepler in the following logogriph[i]:—

smaismrmilmepoetalevmibvnenvgttaviras;

which, being transposed, becomes—

altissimvm planetam tergeminvm observavi;
"I have observed the most distant planet to be tri-form."

As time wore on, more correct ideas were obtained of the phenomenon, which gradually came to be looked upon as due to the existence of two ansæ, or handles, to the planet, though the cause of their disappearance from time to time was yet unexplained. Astronomers are indebted to Mr. C. L. Prince for having called attention to an important stage in the development of true ideas as to the causes of the changes seemingly undergone by Saturn. In 1876 he unearthed and had engraved some curious old drawings made by Gassendi between 1633 and 1656, and published in Gassendi's Works[k]. But it was not till after the lapse of nearly 50 years from the time of Galileo's discovery that the true cause of the appearance seen by him and others became known. C. Huygens was the discoverer, and he intimated his discovery in the following logogriph[l]:—

aaaaaaa	ccccc	d	eeeee	g	h
iiiiiii	llll	mm		nnnnnnnnn	
oooo pp	q rr	s ttttt		uuuuu;	

which letters, when placed in their proper order, give—

annulo cingitur, tenui, plano, nusquam cohaerente, ad eclipticam inclinato;

"The planet is surrounded by a slender flat ring inclined to the ecliptic, but which nowhere touches the body of the planet[m]."

[h] *Opere di Galileo*, vol. ii. p. 152. Padua ed., 1744.

[i] *Opere di Galileo*, vol. ii. p. 40. Padua ed., 1744.

[k] Vol. iii. Lyons, 1658. See *Month. Not.* R.A.S., vol. xxxvi. p. 108, Jan. 1876.

[l] *De Saturni Luna Observatio Nova.* Hagæ, 1656. Followed in 1659 by detailed particulars in the *Systema Saturnium.*

[m] T. Maurice (*Indian Antiquities*, vol. vii. p. 605; see also vol. ii. p. 302) gives an engraving of *Sani*, the Saturn of the Hindus, from an image in an ancient pagoda. A circle is formed around him by the intertwining of two serpents; whence the writer infers that, by some means or other, the existence of Saturn's ring may have been known in remote ages. The same thing is observable in

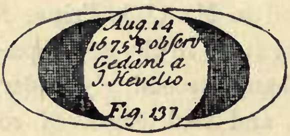
It must not be supposed that this discovery was the result of a chance inspiration. On the contrary, Huygens seems to have spent several years in scrutinising Saturn before he finally decided that the theory of a ring round the planet was the only one which would reconcile the various observed facts.

With the view of commending his hypothesis to the attention of astronomers, Huygens ventured to predict that in the month of July or August 1671 the planet would again appear round; and in this he was nearly correct, for Cassini, watching the disappearance of the ring, found the planet presenting this aspect in May 1671, or within 2 months of the time foretold by Huygens.

Fig. 100.

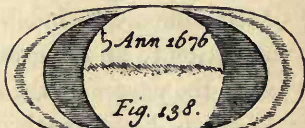
(*Ball*, 1665.)

Fig. 101.



(*Hevelius*, 1675.)

Fig. 102.



(*Cassini*, 1676.)

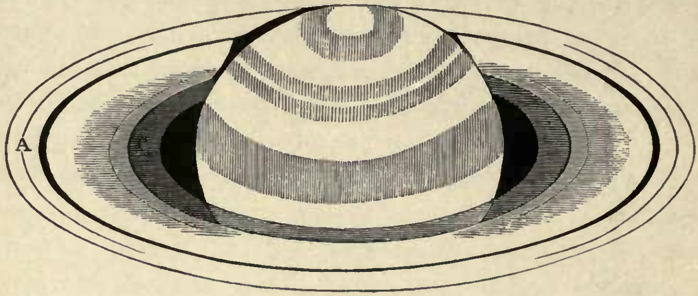
THREE 17TH CENTURY SKETCHES OF SATURN AND ITS RING.

As advances have been made in the manufacture of telescopes, so our knowledge of the Saturnian system has been increased. In 1675, within a very few years of Huygens's discovery, Cassini discovered that what Huygens saw as one ring was in reality a combination of two, lying concentrically, one within the other[n]. Sir W. Herschel was for a long time very unwilling to allow that this division was actually such in fact; and he did not become convinced until he had executed a very protracted series of observations extending over several years. He coupled his acceptance of the division with a strong assertion that it was the only one that existed.

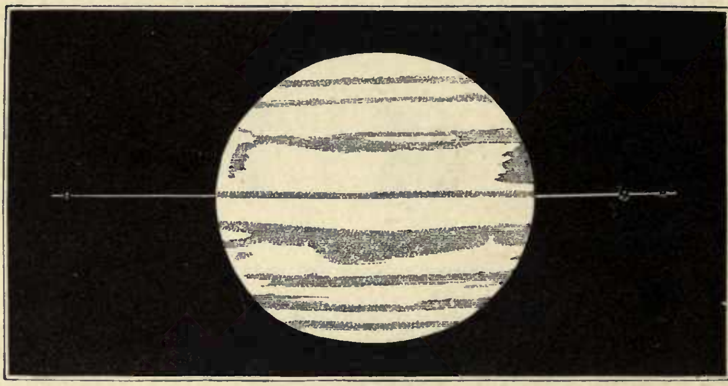
Assyrian sculptures; but it must in candour be added that this ring-surrounded Deity possessed a signification (impossible to be alluded to here) in the ancient Phallic worship.

[n] For some particulars of a controversy which raged in 1882 respecting the share of credit for this discovery supposed to be due to others besides Cassini see *Observatory*, vol. v., 1882, *passim*. It arose out of misconceptions as to the meaning of a passage which appears in *Phil. Trans.*, vol. i. p. 152. Cassini's sketch will be found in Lowthorp's abridgement of *Phil. Trans.*, vol. i. p. 288.

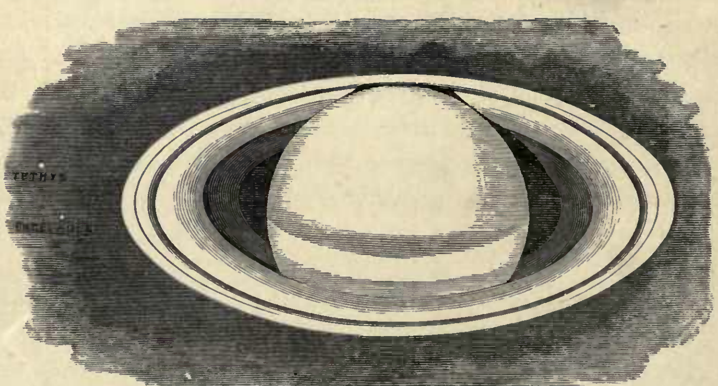
P



1853: Nov. 2. (*Dawes.*)



1848. (*W. C. Bond.*)



1856: Jan. 8. (*Jacob.*)

SATURN.

But we have now certain knowledge of the existence of more than 2 rings, and the system must be described as a *multiple* one.

It is stated by Lalande[o] that Short, the celebrated optician, perceived several concentric streaks on the outer ring. It is not known that Short left any record of his own relating to this.

Between June 19 and 26, 1780, Sir W. Herschel[p] perceived a slight dark streak close to the interior edge of the western ansa. It had disappeared on June 29, and no corresponding appearance at all was seen on the other ansa.

In Dec. 1823 M. Quetelet, at Paris, with a Cauchoix achromatic of 10 inches aperture, thought he saw a division in the exterior ring[q].

On Dec. 17, 1825, Capt. Kater, with a 6-inch Newtonian reflector, perceived in the exterior ring numerous black streaks very close to each other[r]. On Jan. 16, 1826, with another telescope, the same observer saw similar markings, but as on Jan. 22, 1828, none whatever could be perceived, he concluded that they had no permanent existence.

On April 25, 1837, Encke[s], at Berlin, assured himself of the existence of a division in the exterior ring; on May 28 following he was able to procure measurements which shewed that the old ring was unequally divided, the wider portion lying outermost.

On May 29, 1838, Di Vico, at Rome, perceived not only this division, but two similar divisions in the interior ring.

On Sept. 7, 1843, Lassell and Dawes[t] saw a decided division in the exterior ring *at both ends*, but placed it near the *outermost* edge, thereby failing to agree with Encke's measurements of 1837.

This subdivision of the exterior ring is now generally accepted[u], and De La Rue's beautifully executed engraving (Fig. 98, Plate XII) conveys a good idea of it.

[o] *Astronomie*, vol. iii. Paragraph 3228. 2nd ed., Paris, 1771.

[p] *Phil. Trans.*, vol. lxxxii. p. 8. 1792.

[q] *Mem.* R. A. S., vol. iv. p. 388. 1831.

[r] *Mem.* R. A. S., vol. iv. p. 384. 1831.

[s] *Mathematische Abhandlungen der Königl. Akad. Wissenschaften Berlin*, 1838, p. 5.

[t] *Month. Not.*, vol. vi. p. 12.

[u] Jacob on the contrary expressed in unequivocal terms his conviction that the black mark or so-called division in the exterior ring was merely a *depression*. He was confident that it reflected the planet's shadow, shewing an apparent projection, such as every shadow falling

The discovery of another curious and interesting feature has now to be dealt with. In 1838 Galle, in examining Saturn, noticed a gradual shading off of the interior bright ring towards the ball. He published a note of this observation, but little or no attention seems to have been paid to it [x]. On Nov. 11, 1850, G. P. Bond perceived a luminous appearance between the ring and the planet: subsequent observations by himself and his father shewed that this luminous appearance was neither more nor less than another ring. Neither of these observers could satisfactorily determine whether this dusky ring (as it soon came to be called) was actually in contact with the interior bright ring, but they thought it was not [y]. Before the arrival of the American mail conveying intelligence of this new ring, Dawes had found it. On Nov. 29 he entered in his Journal the following remark: "After a few seconds of uncommonly sharp vision, I involuntarily exclaimed, 'Obvious.' There is a *shading*, like *twilight*, at the inner portions of the inner ring [z]." This acute observer was not long in ascertaining the annular character of the "shading," and moreover he found (as did O. Struve also) that the dusky ring was occasionally divided into 2 or more concentric rings. This fact is not indicated in De La Rue's engraving, but the transparent nature of the entire ring is well shewn. On Dec. 3, Lassell, while on a visit to Dawes, saw "something like *a crape veil* covering a part of the sky within the inner ring:" this observation was made in consequence of a hint given by Dawes as to what he himself had seen [a].

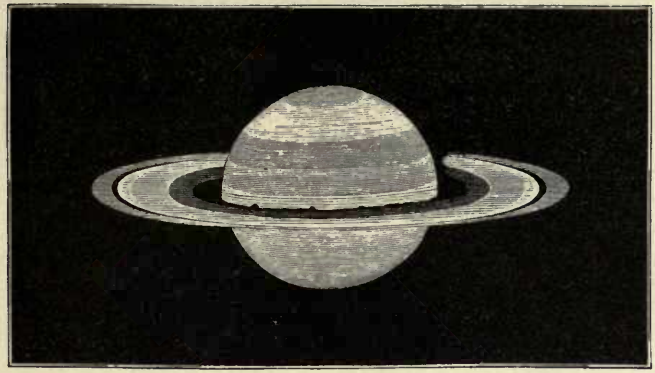
on a groove has. (*Month. Not.*, vol. xvi. p. 126, March 1856; vol. xvii. p. 174, April 1857.) Hippisley and Watson disbelieved in a division, and adhered to the opinion that the mark is merely a mark, and that its breadth varies. *Month. Not.*, vol. xiv. p. 163, March 1854; vol. xvi. p. 152, April 1856.)

[x] *Math. Abhandl. Königl. Akad. Wissenschaften Berlin*, 1838, p. 7. See also *Ast. Nach.*, vol. xxxii. No. 756. May 2, 1851; and *Month. Not.*, vol. xi. p. 184. June 1851.

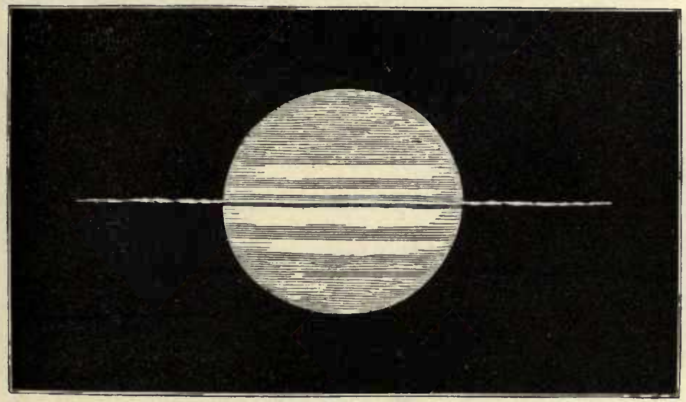
[y] *Mem. Amer. Acad. of Arts and Sciences*, vol. v., (N.S.), p. 111. 1855.

[z] *Month. Not.*, vol. xi. p. 23. Dec. 1830.

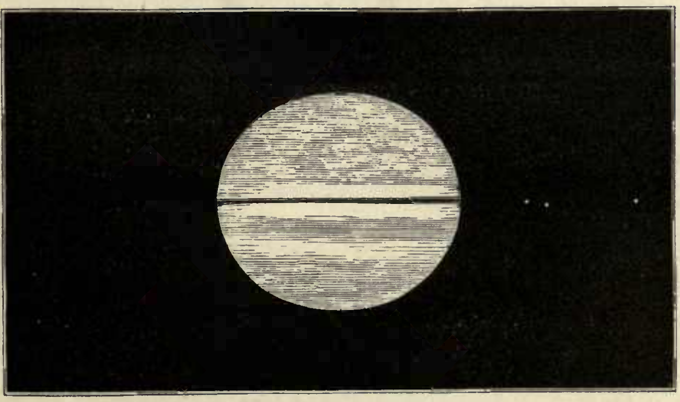
[a] A passage in *Phil. Trans.*, vol. xxxii. p. 385, 1723, by Hadley, almost leads one to infer that he had seen the dusky ring, though without being able to make up his mind as to what it was. Hind, in *Month. Not.*, vol. xv. p. 32, Nov. 1854, expresses his belief that a record of Picard's will fairly bear the interpretation that on June 15, 1673, he saw the dusky ring, with the like comprehension as Galle.



1861: April 7. (*De La Rue.*)

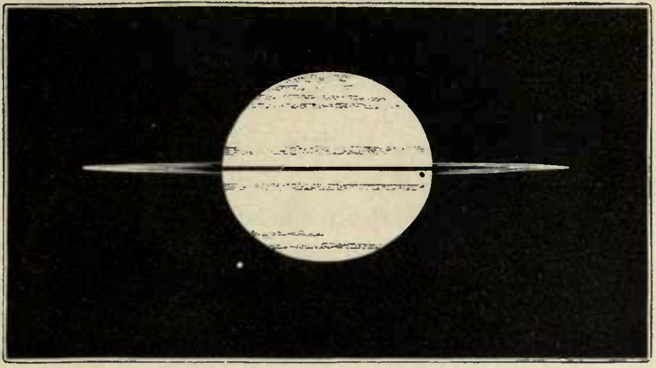


1861: Nov. 12. (*Jacob.*)

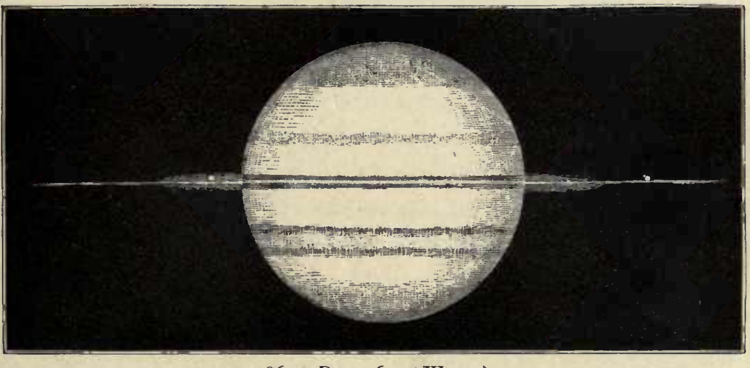


1861: Dec. 4. (*Jacob.*)

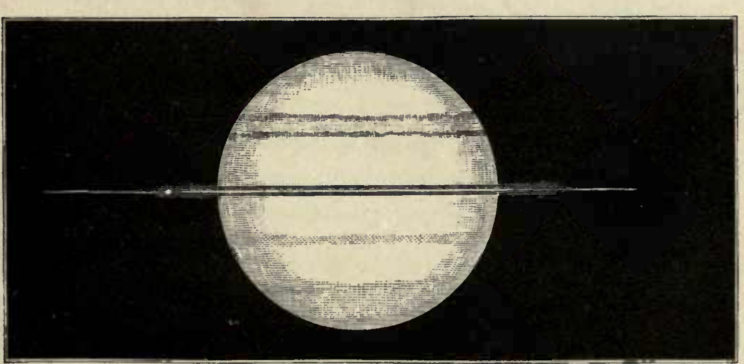
SATURN.



1861: November. (*Anon.*)



1861: Dec. 26. (*Wray.*)



1862: Jan. 5. (*Wray.*)

SATURN.

The transparency of the dusky ring was not ascertained till 1852; Jacob, Dawes, and Lassell share this discovery between them[b].

Figs. 110–11 on Plate XV. relate to a very interesting observation made by Wray on Dec. 26, 1861. He saw—"A prolongation of very faint light stretched on either side from the dark shade on the ball, overlapping the fine line of light formed by the edge of the ring, to the extent of about one-third its length, *and so as to give the impression that it was the dusky ring, very much thicker than the bright rings*, and seen edgewise projected on the sky[c]."

It has been thought that the dusky ring is wider and less faint than formerly. On March 26, 1863, Carpenter found it to be "nearly as bright as the illuminated ring," so much so that it "might easily have been mistaken for a part of it[d]."

On Oct. 29, 1883, Davidson with a 6·4 inch refractor found an undoubted difference in the brightness of the dusky ring at the 2 ansæ, the preceding ansa being decidedly brighter than the following one; different eye-pieces yielded the same result, and another observer concurred in the opinion[e].

Having said this much on the history of these discoveries, some facts connected with the rings must now be set out. Their true form is no doubt circular, or nearly so; but as we always see them foreshortened, they appear more or less oval when the Earth is above or below the plane of the rings, but when we are nearly in the plane they appear as a single straight line, or something like it. When we are exactly in the plane they disappear altogether, except in very large telescopes. Figs. 112 and 113 will make this sufficiently clear. In the true position of the rings during Saturn's revolution round the Sun there is no change: they remain continually parallel to each other.

[b] Perhaps this sentence requires to be qualified, for Galle, in his drawing, represents the planet seen through the ring; but it must be remarked that he did not know he was looking at a *ring*, and only intended to draw what was (and readily might be) taken for a belt on the planet of deeper shade than usual.

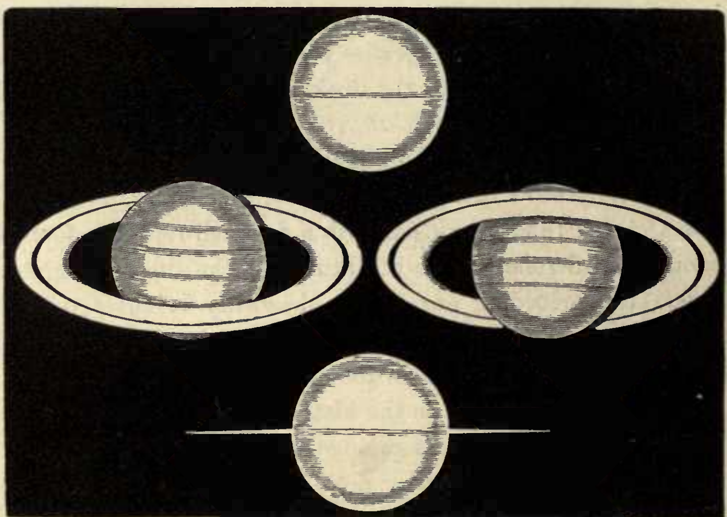
[c] *Month. Not.*, vol. xxiii. p. 86. Jan. 1863.

[d] *Month. Not.*, vol. xxiii. p. 195. April 1863.

[e] *Observatory*, vol. vii. p. 85. March 1884.

The plane of the rings is inclined 28° 10′ to the ecliptic, and intersected it in 1860 in longitude 167° 43′ 10″ and 347° 43′ 10″ (17¾° of Virgo and Pisces); the former point being the place of the ascending node, and the latter that of the descending node. According to Bessel the longitude of the node of the ring referred to the ecliptic increases at the rate of 46·462″ *per annum.*

Fig. 112.



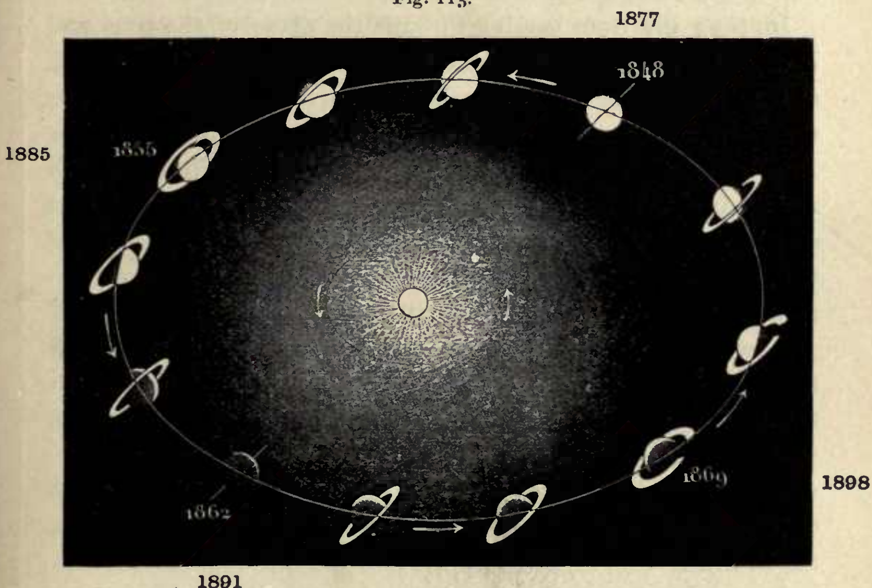
GENERAL VIEW OF THE PHASES OF SATURN'S RINGS.

Whether viewed from the Earth or from the Sun, the phenomena seen in connexion with the rings of Saturn are much the same, but the motion of the Earth in its orbit (the inclination of which differs somewhat from that of Saturn) gives rise to certain phases in the rings which would not be witnessed by an observer placed on the Sun. "Thus it usually happens that there are 2, if not 3 disappearances[f], about the time of the planet's arrival at the nodes. The plane of the ring may not pass through the Earth and Sun at the same time, but the ring may be invisible

[f] There can really never be more than *two* disappearances. (Proctor, *Saturn*, p. 90.)

under both conditions, because its edge only will be directed towards us. It is also invisible when the Earth and Sun are on opposite sides of its plane—a state of things that may continue a few weeks: in this case we have the dark surface turned towards our globe. In very powerful telescopes it has been found that the disappearance of the ring is complete under the latter

Fig. 113.



PHASES OF SATURN'S RINGS AT THE DATES SPECIFIED.

condition; it has, however, been perceived as a faint broken line of a dusky colour, not only when the Sun is in its plane, but likewise when its edge is directed to the Earth. Our remarks must be considered as applying to observations with telescopes in common use." The foregoing quotation is from Hind[g]; a fuller account is given by Sir John Herschel[h].

Saturn's period being $29{\cdot}458^{y}$, the half of this, or $14{\cdot}729^{y}$, will be the average time elapsing between 2 nodal passages. Such a

[g] *Introd. to Ast.*, p. 107.

[h] *Outlines of Ast.*, p. 343 *et seq.*

passage took place in 1877. The Northern surface of the ring had then been visible for $14{\cdot}7^y$.

In June 1885 the planet was in 77.5° of longitude, one of the two places at which the greatest opening of the rings occurs. The breadth will diminish till 1891, when the motion of the planet and of the Earth will again bring the ring edgewise to the Earth and cause it to disappear, the Sun being South of the plane, and the Earth crossing to the North.

In 1893 the Sun, passing through the plane of the ring, will begin to illuminate its Northern surface, and the Earth being also on that side, the ring will reappear. After a few months the Earth will go to the South, and the Sun remaining on the North, a second disappearance will take place. The ring will remain invisible, in consequence of presenting its unilluminated side to us, till the Earth once more passing through the plane of the ring to the North, will bring the Northern side into view—a state of things which will last till 1907.

It will be seen from De La Rue's drawing of 1856, and from others taken at the epoch of maximum breadth, that the ball is at such times entirely encompassed by the ring, and that thus the outline of the whole system is a perfect ellipse: this state of things always lasts for several months. The ring of Saturn is most open when the planet is in either Gemini or Sagittarius.

By a careful examination of the ring Sir W. Herschel ascertained that it revolves round the ball in $10^h\ 32^m\ 15^s$—a period not greatly in excess of that of the planet's own axial rotation: the direction is the same in both cases. There are, however, great difficulties in the way of admitting this rotation [i].

In 1854–5–6, Secchi executed numerous measures of the rings, but they exhibited considerable discordances. He afterwards found that whilst those of 2 consecutive days did not harmonise, those of 3 and 9 days did; and the idea then occurred to him that the results might be explained by supposing the ring to

[i] It is noteworthy that previously to Sir W. Herschel finding the result given in the text, Laplace calculated that the rings *ought* to rotate in $10^h\ 33^m\ 36^s$.

be elliptical, presenting sometimes its longer, sometimes its shorter diameter. He failed to reconcile Herschel's period of rotation with his own observations, but found that a period which corresponds with that which a satellite placed on the margin of the ring would have (namely, $14^h\ 23^m\ 18^s$) would satisfy them[k].

O. Struve introduced a system for conveniently distinguishing the rings from each other, in writing and speaking, which is now generally adopted. He called the exterior bright ring **A**, the interior bright ring **B**, and the dusky one **C**. When reference is made to the system as a whole it is very usual to say 'ring,' in the singular number, no one ring in particular being thereby meant.

The ring is not concentric with the ball. Gallet of Avignon announced this in 1664, placing the ball nearer to the East ansa.

In 1827, Schwabe expressed his belief that the ring was eccentric, but in the opposite direction to that assigned by Gallet. Harding confirming Schwabe's opinion, W. Struve took the matter in hand micrometrically, and found that at the mean distance of Saturn from the Earth, whilst the diameter of the Eastern vacuity was 11·288″, that of the Western was only 11·073″, shewing a difference of 0·215″ in favour of the former. This peculiarity has been shewn to be essential to the stability of the system of the rings: without this feature and without rotation they would fall upon the planet.

The following angular measurements, reduced to the mean distance of the planet (and calculated on the solar parallax of 8·80″), are by the same observer:—

	″		English Miles.
Outer diameter of exterior ring	40·095	=	172,240
Inner diameter ,, ...	35·289	=	151,590
Breadth ,, ...	2·403	=	10,320
Outer diameter of interior ring	34·475	=	148,100
Inner diameter ,, ...	26·668	=	114,560
Breadth ,, ...	3·903	=	16,765
Interval between the two	0·408	=	1,750
Distance of ring from ball	4·339	=	18,640
Equatorial diameter of ball	17·60	=	75,600

[k] *Month. Not.*, vol. xvi. p. 52. Jan. 1856.

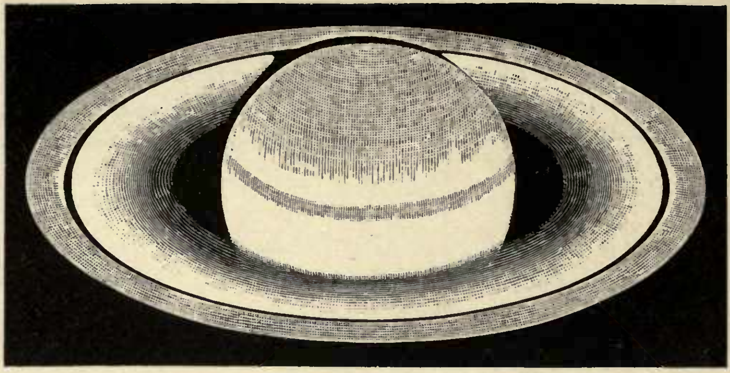
The measures of De La Rue[l], Main[m], and Jacob[n] are appended for comparison[o]:—

	De La Rue.	Main.	Jacob.
		"	"
Outer diameter of exterior ring	39·83	39·73	39·99
Inner diameter ,, ...	35·33		35·82
Breadth ,, ...	2·25		2·08
Outer diameter of interior (middle) ring	33·45		34·85
Inner diameter ,, ,, ...	26·91	27·65	26·27
Breadth ,, ,, ...	3·27		4·29
Interval between the two	0·94		0·48
Distance of ring from ball	4·62	5·07	4·16
Equatorial diameter of planet	17·66	17·50	17·94

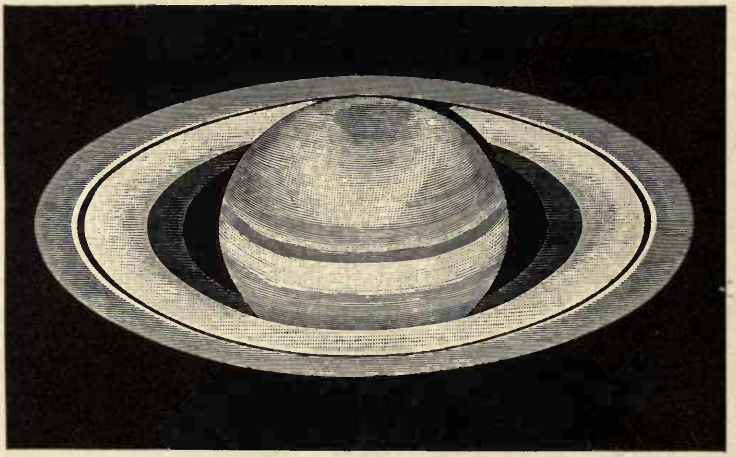
There are some particulars relating to the rings which cannot well be classified. Sir J. Herschel estimated their thickness at not more than 250 miles; G. P. Bond cut this down to 40 miles. Peirce[p] thought that there were good grounds for supposing them to be fluid rather than solid; but the opinion which meets with most favour now is that they are a dense aggregation of small satellites, densest where brightest, widest apart where most faint. In fact it may be shewn that if a system of rings of such proportion was constructed of iron it must become semi-fluid under the forces it would experience. Considered as a system, the rings are sensibly more luminous than the planet (a fact which Hooke pointed out as long ago as 1666), and **B** is brighter than **A.** **B** itself is perceptibly less bright at its inner edge than elsewhere. At the epoch of the Saturnian equinoxes the ansæ do not both disappear and reappear at the same time, and at these periods they are sometimes of unequal magnitude.

On Oct. 9, 1714, 6 days before the actual passage of the Earth through the plane of the ring, and whilst the ansæ were decreasing, Maraldi noticed that the Eastern one appeared a little

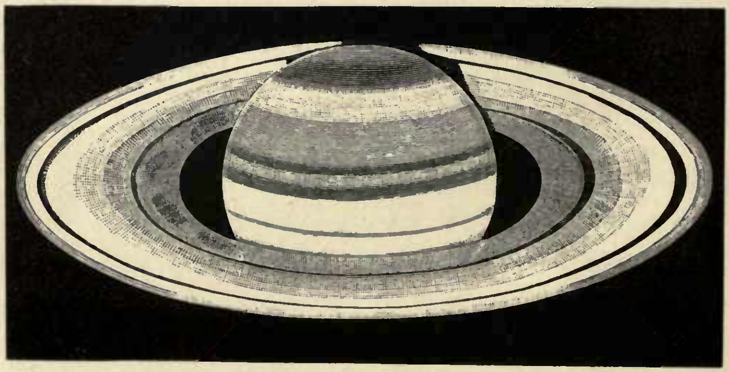
[l] *Month. Not.*, vol. xvi. p. 43. Dec. 1855.
[m] *Ibid.*, p. 30.
[n] *Ibid.*, p. 124 (March 1856).
[o] An important series by Bessel will be found in *Ast. Nach.*, vol. xii. Nos. 274–5. Feb. 18, and March 7, 1835.
[p] *Gould's Astronomical Journal*, vol. ii. p. 17. June 16, 1851.



DURING THE WINTER OF 1883–4. (*Ranyard.*)



Feb.–March, 1884. (*Henry.*)



Feb. 1887. (*Terby.*)

SATURN.

broader than the other for 3 or 4 nights, and yet it vanished first[q]. He was induced to suspect that the ansæ had changed places by rotation, and that at any rate the surface of the rings was very irregular, the 2 rings lying moreover in different planes.

Heinsius, Varela, Messier, and many others have noticed the ansæ to be of different lengths, and that one is frequently visible without the other. When only one is visible, it is most frequently that on the Western side—a fact for which it is difficult to account.

Fig. 116 represents Saturn as drawn by Terby of Louvain with an 8-inch Grubb Refractor. He remarks that the drawing brings out especially the following features:—Encke's division; Henry's bright streak in ring **A** opposite Cassini's division; Struve's division between rings **B** and **C** especially on the East; the black patches in the dusky ring especially on its West side; the indentation of the shadow of the ball on the Cassini division on the West; the shadow cast by the ball on the dusky ring; and lastly the transparency of the dusky ring which permits the ball to be seen through it[r].

When at its nodes the ring frequently appears broken, shewing merely luminous elongated beads seemingly detached from one another. For a long time astronomers were in doubt as to the cause of these appearances, and it was not till so recently as 1848 that the question was cleared up. In that year the observers at Harvard College, U. S., instituted a careful inquiry, and their micrometrical observations shewed that these "beads" were due to the concurrent effect of light reflected by the edges, external and internal, of the rings. The Figures [117–18] are copied from Bond's memoir, but ring **C** is omitted that matters may be simplified. What follows I cite from Webb, who devoted much time to the elucidation of Saturnian facts. "It must be borne in mind that this design is an intentional exaggeration for clearness' sake, representing the dark surface much

[q] *Mém. Acad. des Sciences,* 1715, p. 12.
[r] *Observatory,* vol. x. p. 163, April 1887.

more expanded than it ever really is, and the thickness of the rings many (they say perhaps 10) times too great. To this they add the qualification that the edges should be rounded;

Fig. 117.

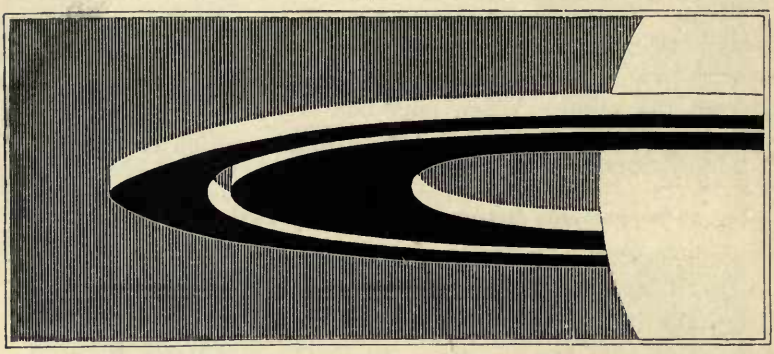


DIAGRAM ILLUSTRATING THE PHENOMENON OF SATURN'S RING "BEADED."

and I should be inclined to suggest another, that **A** may probably be much thinner than **B**, so that its inner edge would add

Fig. 118.

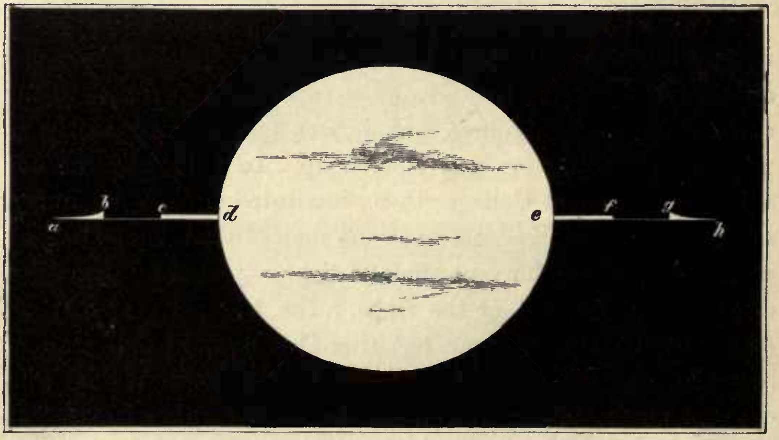


DIAGRAM ILLUSTRATING THE PHENOMENON OF SATURN'S RING "BEADED."

little to the effect. Comparing, then, Fig. 117 with Fig. 118, we should have,—1. A narrow dark band upon the planet, slightly curving upwards, and consisting of both the dark side, of the ring and its shadow (the latter not inserted in Fig. 114). 2. The outer edge of **A** visible throughout, but with extreme difficulty when alone, as between *b* and *c*, and *f* and *g*, and towards *a* and *h*. 3. Two brighter portions from *c* to *d*, and from *e* to *f*, where the light of **A** is reinforced by that reflected by the inner edge of **B**. 4. Two bright knots where the same light, strengthened by the concurrent reflection from the inner edge of **A** and the outer of **B** (the latter, it may be presumed, many times outweighing the former), reaches us through the opening of [Cassini's] division. This the Americans considered fully satisfactory, the curvature of the black stripe having been noticed, and estimated at 0·25″; the extremities of the line, and the beads, falling beneath its direction, as from the diagram they ought to do, and the accordance of measures fully bearing out the impression of Nov. 3, that the 'interruptions in the light of the ring are so plainly seen, that no one could for a moment hesitate as to their explanation.'"

O. Struve many years ago propounded a theory[s] that the rings were expanding inwards (so that ultimately they would come in contact with the ball); and also that between the time of J. D. Cassini and Sir W. Herschel the breadth of the inner ring had increased in a more rapid ratio than that of the outer ring, while the exterior diameter of **A** was unchanged. Struve drew this conclusion from the early observations of Huygens and others: but it is doubtful if these are to be relied upon; and Main considered that micrometric measures obtained by himself showed the theory to be untenable. Kaiser also considered it to be destitute of foundation[t]. On the other hand, both Hind[u] and Secchi[x] favour the idea of change.

The rings cast a shadow; and from observing this shadow

[s] *Mém. de l'Acad. des Sciences de St. Pétersbourg*, 6th ser., Math. et Phys., vol. v. 1852. An abstract of it appears in *Month. Not.*, vol. xiii. p. 22. Nov. 1852.

[t] See *Month. Not.*, vol. xvi. p. 66, Jan. 1856, for an abstract of Kaiser's memoir.

[u] *Month. Not.*, vol. xv. p. 31. Nov. 1854.

[x] *Month. Not.*, vol. xvi. p. 50. Jan. 1856.

some persons have been led to think that the surfaces of the rings are convex[y], and that they do not lie in precisely the same plane. Sir J. Herschel doubted the former being a legitimate conclusion from *observation*, but admitted its theoretical probability[z]. Lassell considered that **C** often changes colour, *each* end being alternately bluish-gray and brownish[a]. This may indicate rotation. Hippisley thought that there was evidence that the ring **A** lies in a different plane from the others, and that **B** is thicker in the middle than at either of the edges[b]. Sir W. Herschel surmised that the ring is not flat, but that the inner edge was hemispherical or hyperbolical[c]. The outer edge of **B** is commonly the brightest portion of the system, but Schwabe and Webb believed it to be variable. The inner edge of the same ring is usually much the dullest, but occasionally it brightens up. G. P. Bond in 1856 regarded the dark shading visible at the inner edge of **B** as a sharply-defined dark area, elliptical in form and concentric with the rings, but of greater eccentricity. Prince "is convinced" that **C** is becoming more and more illuminated[d]. Lassell and De La Rue have suspected the existence of mountains on the rings, in consequence of elevations appearing in the shadow projected on the ball[e]. [Fig. 106, Pl. XIV.] Jacob saw the effect, but doubted the assigned cause, preferring to think that it is an illusion arising from inequalities in the depth or tone of the shadow[f]. In 1848, when the unilluminated side was turned towards us, Dawes saw traces of the shadow, of a coppery hue, and he regarded this as an effect due to a rather dense atmosphere[g]: but more than this, the atmosphere causing a refraction of the solar light on each side of the ring would reduce the shadow of the ring to a penumbra, and thus account for it being imperceptible when the *Sun* was in the plane of the ring. Sir W. Herschel

[y] De La Rue's drawing forcibly conveys the impression of this as regards B.

[z] *Outlines of Ast.*, p. 343.

[a] *Month. Not.*, vol. xiii. p. 147. March 1853.

[b] *Month. Not.*, vol. xiv. p. 163. March 1854.

[c] *Phil. Trans.*, vol. xcvi. p. 463. 1806.

[d] *Month. Not.*, vol. xx. p. 212. March 1860.

[e] *Ibid.*, vol. xxi. pp. 177 and 236. April and June 1861.

[f] *Ibid.*, vol. xxi. p. 237. June 1861.

[g] *Month. Not.*, vol. x. p. 46, December 1849, and vol. xxii. p. 298, June 1862.

had previously believed that an atmosphere surrounding the ring alone would explain a distortion which he noticed in 1807, at the South pole, in optical proximity to the ring; the other pole being at the same time clear of the ring and free from distortion[h].

Between 1872 and 1876, using the 26-inch refractor of the Washington observatory and 2 smaller instruments, Trouvelot spent much time in carefully studying the planet Saturn. His observations were numerous, and the conclusions he drew, important. The following are some of them in a condensed form[i]:—The inner margin of $\mathbf{A}_2$, limiting the outer border of the principal division, shewed on the ansæ some singular dark angular forms attributable to an irregular and jagged conformation of the inner border of $\mathbf{A}_2$, either permanent or temporary; the surface of $\mathbf{A}_1$, $\mathbf{A}_2$ and **B** frequently exhibited a mottled or cloudy appearance on the ansæ; the thickness of the system of rings increases from the inner margin of **C** to the outer margin of **B**, a fact which is shown by the form of the planet's shadow thrown upon the rings; the cloud-forms seen near the outer edge of **B** attain different heights and change their relative position either by the rotation of the rings on an axis, or by some local cause—a fact indicated by the rapid changes in the indentation of the shadow of the planet; the inner portion of **C** disappears in the light of the planet at that part which is projected upon its disc; contrary to the observations hitherto made, **C** is not transparent throughout; **C** grows more dense as it recedes from the planet, so that at about the middle of its width the limb of the planet entirely ceases to be visible through it; the matter composing **C** is agglomerated here and there into small masses which almost wholly prevent the light of the planet from reaching the observer.

[h] *Phil. Trans.* vol. xcviii. p. 162. 1808.

[i] *American Journal of Science and Arts*, 3rd Ser., vol. xii. p. 447. June 1876. Trouvelot has adopted a special nomenclature of his own which is calculated to cause great confusion. He designates by A and B the outer and inner portions of the outer king, and calls C the ring which all other astronomers, following O. Struve, always indicate by the letter B. I have altered Trouvelot's letters to accord with the recognised nomenclature, indicating the sub-divisions of A by calling them A_1 and A_2 respectively.

In February and March 1884 the brothers Henry, using at the Paris Observatory a refractor of 15 inches aperture, armed with a power of 1000, remarked around the inner edge of **A** a narrow bright ring bounded by a black line. This new ring, not (it would seem) previously noted, was about 1·5″ wide; in other words, was about as wide as Cassini's well-known division. But the fact which especially struck these observers was the non-visibility of Encke's great division in **A**. That division, so familiar to all who have observed and drawn Saturn during the last 50 years, had in the judgment of MM. Henry completely disappeared. They stated that nothwithstanding very favourable atmospheric conditions it was impossible to detect on **A** any markings but the narrow bright circle mentioned above[k]. The disappearance of Encke's division seems to have been lately remarked in America.

The following observations of Saturn by Keeler with the great 36-inch telescope of the Lick observatory present some very interesting and novel points :—

"The object of greatest interest to me was the outer ring. It is usually drawn with a division at about one-third of its width from the outer edge, sometimes fine and sharp and sometimes broad and indefinite. Many drawings which I have examined place this line or shade near the centre of the ring. In a series of drawings which I made with the 12-inch equatorial of this observatory, from a careful study of Saturn during the finest nights of the past summer [1887], the outer ring is represented with a faint broad shading in the centre, diminishing gradually toward the edges, which are therefore relatively bright.

"The 36-inch equatorial shewed, at a little less than one-fifth of the width of the ring from its outer edge, a fine but distinct dark line, a mere spider's thread, which could be traced along the ring nearly to a point opposite the limb of the planet. This line marked the beginning of a dark shade which extended inwards, diminishing in intensity nearly to the great black division. At its inner edge the ring was of nearly the same brightness as outside the fine division. No other markings were visible.

"It is easy to see how, with insufficient optical power, this system of shading could present the appearance of an indistinct line at about one-third the width of the ring from its outer edge. The broad band alone would make it appear near the centre of the ring, and the effect of the line, itself invisible, would be to displace the greatest apparent depth of shade in the direction of the outer edge. Two nights after the observations just described I re-examined Saturn very carefully with the 12-inch equatorial, but could not perceive the narrow line, although I was then aware of its existence, and the definition was excellent[l]."

[k] *L'Astronomie*, vol. iii. p. 230. June 1884.
[l] *Sid. Mess.*, vol. iii. p. 80. Feb. 1888.

In general the brightness of the ball and of the rings is tolerably uniform, but there are exceptions to this rule. In April 1862 Lassell noted the rings to be very dull compared with the ball, but this might have been due to the small elevation of the Sun above the plane of the ring. Probably any peculiarities of this nature which may be noticed from time to time are optical effects, and do not depend on actual change. Trouvelot however found the ball less luminous at its circumference than at its centre, a fact which seems indicative of the existence of an atmosphere.

Bessel entered upon some investigations to determine the mass of the rings, by ascertaining their perturbing effect on the orbit of the 6th satellite, Titan. He estimated it at $\frac{1}{118}$ of the mass of the planet[m]. The thickness of the rings being too minute for measurement, no precise determination of their density is attainable; if, however, we assume it as approximately equal to that of the planet, as is probably the case, it will follow that the thickness is about 138 miles—a quantity which is very nearly the mean of the 2 estimations of Sir J. Herschel and Bond. Supposing this to be correct, at the mean distance of the planet the rings would only subtend an angle of about 0·03″; it may therefore be readily inferred that the ring will at stated times become wholly invisible even in the most powerful telescopes.

Saturn is attended by 8 satellites, 7 of which move in orbits whose planes coincide nearly with that of the planet's equator, and therefore with the plane of the rings also: the orbit of the remaining and most distant satellite is inclined about 12° 14′ (Lalande) to the aforesaid plane. One consequence of this coincidence in the planes of the orbits of the first 7 satellites is that they are always visible to the inhabitants of both hemispheres when not under eclipse in their primary's shadow.

In dealing with the satellites of Saturn, I continue to follow my usual plan of tabulating as much information as possible, but when we have proceeded beyond Jupiter, data concerning

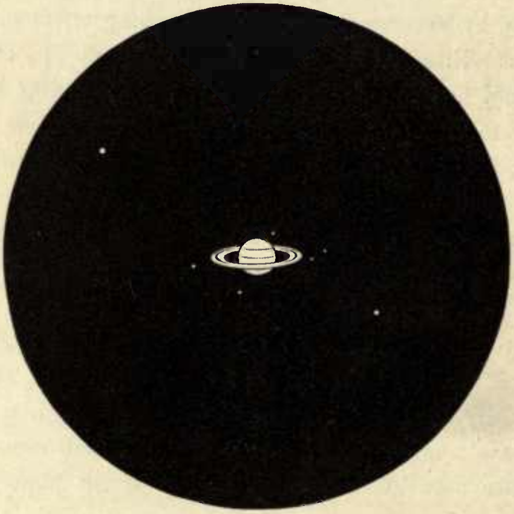
[m] *Conn. des Temps*, 1838, p. 29.

satellites become both scarce and contradictory, and it is frequently necessary to give alternative statements.

The figures in the column of "Diameter" are, with the exception of Titan's, extremely doubtful, and this impairs the value of Proctor's calculations given at the foot of the Table opposite.

Mimas. Beer and Mädler's reduction of Sir W. Herschel's observations in 1789 gives for the epoch of Sept. $14^d\ 13^h\ 26^m$ Slough M.T., the Saturnicentric λ at 264° 16′ 36″, the longitude of the peri-saturnium at 104·42°, and the eccentricity at 0·068.

Fig. 119.



GENERAL VIEW OF SATURN AND ITS SATELLITES.

Enceladus. Beer and Mädler, also from Sir W. Herschel's observations, gave for the epoch of 1789, Sept. $14^d\ 11^h\ 53^m$, the λ at 67° 56′ 26″: they considered the orbit to be circular in the plane of the ring. Hind says that Enceladus was *seen* by Sir W. Herschel on Aug. 19, 1787.

Tethys. Lamont, from his own observations in 1836, found for the epoch of April $23^d\ 8^h\ 27^m$ Greenwich M.T., the λ to be 158° 31′, the longitude of the peri-saturnium 357° 37′, the ☊ 184° 36′, the eccentricity 0·0051, and the inclination of the orbit to the

THE SATELLITES OF SATURN.

Names.	Order of Discovery.	Discoverer.		Mean Distance.			Sidereal Period.		E. of orbit.	Diameter.		App. Diam. of ♄ seen from Satel.	App. Star Mag.
				Apparent.	Rad. of ♄	Miles.				⊕ = 1.	Miles.		
				′ ″			d. h. m.	d.				°	
1. Mimas ...	7	Sir W. Herschel.	1789, Sept. 17	0 26·78	3·070	115,100	0 22 37	0·94	0·069	0·12	1001	33	17
2. Enceladus	6	,,	1789, Aug. 28	0 34·38	3·940	147,750	1 8 53	1·37	Uncertain.	...	?	26	15
3. Tethys ...	5	J. D. Cassini.	1684, March	0 42·57	4·880	183,000	1 21 18	1·88	0·005	0·07	500	21·2	13
4. Dione ...	4	,,	1684, March	0 54·54	6·250	234,400	2 17 41	2·73	0·020	0·07	500	16·6	12
5. Rhea ...	3	,,	1672, Dec. 23	1 16·16	8·720	327,300	4 12 25	4·51	0·023	0·17	1200	12·0	10
6. Titan ..	1	C. Huygens.	1655, Mar. 25	2 56·55	20·220	758,700	15 22 41	15·94	0·029	0·42	3300	5·2	8
7. Hyperion	8	W. Bond and Lassell.	1848, Sept. 19	3 33·3	24·430	916,700	21 7 7	21·29	0·115	...	?	4·2	17
8. Iapetus ...	2	J. D. Cassini.	1671, Oct. 25	8 34·52	58·940	2,221,100	79 7 53	79·33	0·025	0·26	1800	1·8	9

It is understood that Dawes claimed to share with Lassell the English discovery of Hyperion, those observers being in company, on the said 19th of September, 1848.

"According to the best estimates of their magnitude, the 8 satellites, taken in their order from the planet, cover spaces on the Saturnian heavens which bear to the space covered by our Moon the respective proportions of about 2, 1, $1\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{8}$, $\frac{1}{100}$, $\frac{1}{40}$. In all, then, they cover an area about 6 times that of our Moon; and as, owing to their great distance from the Sun, they are illumined by only $\frac{1}{100}$th of the light which illuminates our Moon, they could only send back to the planet, if it were possible for them to be all full together, about $\frac{1}{18}$th part of the light we receive from the full Moon."—(Proctor, *Other Worlds than Ours*, p. 154.)

plane of the ring 1° 33′. Sir John Herschel, about the same time, found the λ to be 313° 43′, the longitude of the peri-saturnium to be 53° 40′, the eccentricity 0·04217, and the orbit to be precisely in the plane of the ring. The serious differences in these two results are to be ascribed to errors in the observations arising from the difficulty attending them, but such differences naturally make us distrust the entire batch of figures.

Dione. Sir John Herschel in 1836 found the λ to be 327° 40′, the longitude of the peri-saturnium 42° 30′, the eccentricity 0·0206, and the orbit to be precisely in the plane of the ring.

Rhea. Sir John Herschel in 1835–7 found the λ to be 353° 44′, the longitude of the peri-saturnium 95°, and the eccentricity 0·02269. The inclination is very small.

Titan[n], as the satellite most easily seen, has naturally received most attention. Bessel's determination of its orbit is reputed to be the most complete. For the epoch of 1830·0 he gave the λ at 137° 21′, the longitude of the peri-saturnium at 256° 38′, and the eccentricity 0·029314. The line of apsides has a direct motion on the ecliptic of 30′ 28″ annually, completing a revolution in 718 years, the nodes completing a revolution in 3600 years.

Hyperion has been so recently discovered that its orbit has not been very fully investigated. From Washington observations made in 1875 Hall found the λ to be 120° 12′, the longitude of the peri-saturnium 173°, the eccentricity 0·118, and the inclination of the orbit 6° 12′. Lassell's observations made at Malta in 1852 and 1853 agree with these conclusions in part, but Hall remarks that neither Lassell's observations nor those at Washington "fix the position of the satellite in its orbit with much certainty, since

[n] When Huygens discovered this satellite in 1655, he was imprudent enough to predict that there were no others, because Titan being the 6th secondary planet, and there being only 6 primary planets known, Nature's (supposed) laws of symmetry were satisfied. The danger of prediction in matters of this kind is well illustrated in the case of Mr. John Harris, F.R.S. That learned gentleman published a book in 1729, in which he says: "'Tis highly probable that there may be more than 5 moons revolving round this remote planet [the number of satellites which Saturn was then known to possess]; but their distance is so great as that they have hitherto escaped our eyes, and perhaps may continue to do so for ever; *for I do not think that our telescopes will be much further improved!!*"

Fig 120. *Plate* XVII.

PLAN OF THE SATURNIAN SYSTEM.

they were made when the plane of the orbit was nearly edgewise to the observer." He adds:—"If we examine the elements we shall see that Hyperion moves nearly in the plane of the orbit of Titan, and considering the values of the eccentricities it will be seen that these satellites can approach very near each other[o]." Hyperion was seen by Bond on Sept. 16, 1847, and by Lassell on Sept. 18, but it was not till the date given in the table that its character was determined.

Iapetus. Lalande for the epoch of 1790 gave the λ at 269° 37′, and the ☊ at 150° 27′, reckoned *on the orbit.*

The following elements are by Captain Jacob[p]:—

	1857. Jan. 0. λ	π	☊	ι To Eclip.	ε	Semi-axis maj. a	Daily Sat'centric Mot. μ
	° ′	° ′	° ′	° ′		″	°
Mimas......	210 ±	?	?	?	?	?	381·947
Enceladus	301 55	?	?	?	?	?	262·732
Tethys......	281 42	109 7	167 37	28 10	0·01086	42·60	190·697
Dione	115 30	145 4	167 37	28 10	0·00310	54·85	131·534
Rhea	288 43	185 0	167 19	28 8	0·00080	76·13	79·690
Titan	299 42	257 6	167 58	27 36	0·027937	176·90	22·577
Hyperion	?	?	?	?	?	?	?
Iapetus ...	78 9	349 20	143 1	18 37	0·028443	514·96	4·538

A. Hall considers that the orbits of the 5 inner satellites are sensibly circular and that they move in the plane of the ring or nearly so, but it will be readily understood that the small apparent size of most of these satellites, and the consequently limited number of telescopes and observers which can be brought to bear on them, materially retards the attainment of any more perfect acquaintance with their motions, though it is reasonable to hope that the multiplication of large instruments and experienced observers now taking place will ere long lead to a development of our knowledge of the orbits of these satellites.

[o] *Ast. Nach.*, vol. xcv. No. 2263. June 17, 1879.

[p] *Month. Not.*, vol. xviii. p. 1. Nov. 1857.

Sir J. Herschel pointed out the curious circumstance that the period of Mimas is $\frac{1}{2}$ that of Tethys, and the period of Enceladus $\frac{1}{2}$ that of Dione[q]. Monck puts these facts in the shape that the ratio of these 4 periods are 2, 3, 4 and 6, adding that the period of Iapetus is very nearly 5 times that of Titan. D'Arrest further called attention to the commensurability within $\frac{1}{10}^{d}$, or $2\frac{2}{5}^{h}$, of 274 revolutions of Mimas, 170 of Enceladus, and 85 of Dione[r].

Kirkwood has discovered a still more complicated relationship, which may be thus enunciated: To 5 times the daily angular motion in its orbit of Mimas add the daily motion of Tethys, and 4 times the daily motion of Dione, and the sum total will be equal to 10 times the daily motion of Enceladus.

The disappearance of the ring, in 1862, was taken advantage of by various observers for watching the rare phenomenon of a transit of the shadow of Titan across the planet. The satellite itself was not seen on any occasion, but Dawes and others obtained several good views of the shadow[s]. Again in 1877 the shadow of Titan was seen by Common, and others. The only observation of this kind prior to 1862 appears to have been made by Sir W. Herschel on Nov. 2, 1789. Dawes on May 25, 1862, saw an eclipse of this satellite in the shadow of Saturn—the only instance on record.

It must not be supposed that Titan is the only satellite of which an eclipse, transit, or occultation is possible, for all the satellites are occasionally subject to these effects. This is especially true of the two innermost ones, but the small apparent size of all except Titan hinders observation of them.

Celestial phenomena on Saturn must possess extreme grandeur and magnificence, the rings forming a remarkable series of arches stretched across the Saturnian heavens. The nearest satellite, Mimas, traverses its orbit at the rate of 16′ of arc in a minute of time, so that, as viewed from Saturn, it moves in 2 minutes over a space equal to the apparent diameter of the Moon. Considering

[q] *Month. Not.*, vol. vii. p. 24. Dec. 1845.

[r] *Ast. Nach.*, lvii. No. 1364. June 14, 1862.

[s] *Month. Not.*, vol. xxii. pp. 264, 297, &c. May and June 1862.

the remoteness of Saturn from the Sun its satellites play a somewhat important part in the Saturnian sky as reflectors of sun-light. Nevertheless the space occupied by all of them, taken together, is (as stated on a previous page) only about 6 times that covered by the Moon.

Lockyer thus summarises the phases of Saturn's ring as seen by an observer placed on the planet itself[t]:—"As the plane of the ring lies in the plane of the planet's equator, an observer at the equator will only see its thickness, and the ring therefore will put on the appearance of a band of light passing through the East and West points and the zenith. As the observer, however, increases his latitude either North or South, the surface of the ring-system will begin to be seen, and it will gradually widen, as in fact the observer will be able to look down upon it; but as it increases in width it will also increase its distance from the zenith, until in lat. 63° it is lost below the horizon, and between this latitude and the poles it is altogether invisible. Now the plane of the rings always remains parallel to itself, and twice in Saturn's year—that is, in two opposite points of the planet's orbit—it passes through the Sun. It follows, therefore, that during one-half of the revolution of the planet one surface of the rings is lit up, and during the remaining period the other surface. At night, therefore, in one case, the ring-system will be seen as an illuminated arch, with the shadow of the planet passing over it, like the hour-hand over a dial; and in the other, if it be not lit up by the light reflected from the planet, its position will only be indicated by the entire absence of stars.

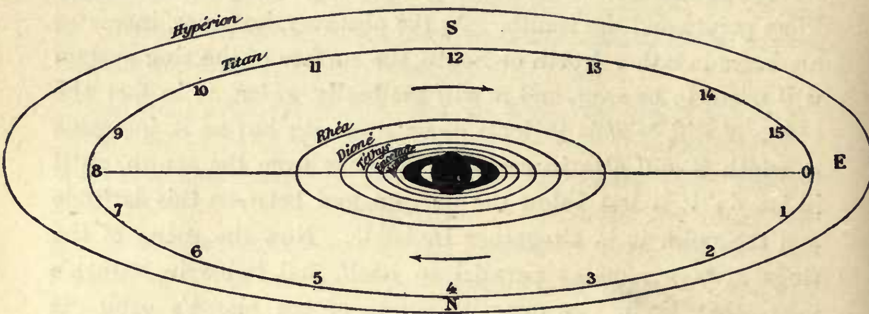
"But if the rings eclipse the stars at night, they can also eclipse the Sun by day. In latitude 40° we have morning and evening eclipses for more than a year, gradually extending until the Sun is eclipsed during the whole day—that is, when its apparent path lies entirely in the region covered by the ring; and these total eclipses continue for nearly 7 years: eclipses of one kind or another taking place for 8 years 292 days. This will give us an idea how largely the apparent phenomena of the

[t] *Elementary Lessons in Astronomy*, p. 117.

heavens, and the actual conditions as to climates and seasons, are influenced by the presence of the ring."

The only physical fact which has been discovered in relation to the satellites of Saturn concerns Iapetus. Cassini lost that satellite soon after its discovery, but a larger telescope enabled him to find it again, and moreover to ascertain that it was subject to considerable variations of brilliancy. Sir W. Herschel, with a view of establishing this fact beyond doubt, paid much

Fig. 121.



THE APPARENT ORBITS OF THE SEVEN INNER SATELLITES OF SATURN TO FACILITATE THEIR IDENTIFICATION (1888).

*** *The date of Titan's Eastern Elongation being known (= 0), it will on subsequent days be found in the positions corresponding to the daily intervals marked on the diagram.*

attention to Iapetus. He was able to confirm Cassini's opinion, and decided that it actually did experience a considerable loss of light when traversing the Eastern half of its orbit. He found that 7° past Opposition was the place of minimum light. The conclusions deducible from this are (as Cassini himself pointed out), that the satellite rotates once on its axis in the same time that it performs one revolution round its primary; and that there are portions of its surface which are almost entirely incapable of reflecting the rays of the Sun.

The mass of Saturn has been given at $\frac{1}{3021}$ by Newton; at $\frac{1}{3359}$ by Laplace; at $\frac{1}{3512}$ by Bouvard; and at $\frac{1}{3500.5}$ by Bessel. Jacob thought from his own observations that the mass of the whole Saturnian system did not differ much from $\frac{1}{3475}$. The most recent value is A. Hall's, $\frac{1}{3478}$.

"The most ancient observation of Saturn which has descended to us was made by the Chaldæans, probably at Babylon, in the year 519 of Nabonassar's period, on the 14th of the month *Tybi*, in the evening; when the planet was observed to be 2 digits below the star in the Southern wing of Virgo, known to us as γ Virginis. The date given by Ptolemy, who reports this observation in his *Almagest* [lib. xi.], answers to B.C. 228, March 1[u]."

An occultation of this planet by the Moon is recorded to have been observed by one Thius, at Athens, on Feb. 21, 503 A.D.

Cassini observed in 1692 the occultation of a star by Saturn's satellite Titan. No other instance of this kind is on record.

From Saturn the Sun appears only about 3′ in diameter, and the greatest elongations of the planets are: Mercury, 2° 19′; Venus, 4° 21′; Earth, 6° 1′; Mars, 9° 11′; Jupiter, 33° 3′—so that a Saturnian, assuming his visual powers to resemble ours, can only see Jupiter, Uranus, and Neptune with the naked eye, and Mars perhaps with some optical aid. Saturn, on account of its slow dreary pace, was chosen by the alchemists as the symbol for lead.

In computing the places of Saturn, the Tables of A. Bouvard, published in 1821, were long used, but new Tables by Le Verrier have superseded them. Tables of the satellites have still to be formed, and are a great desideratum.

[u] Hind, *Sol. Syst.*, p. 117.

CHAPTER XIII.

URANUS. ♅

Circumstances connected with its discovery by Sir W. Herschel.—Names proposed for it.—Early observations.—Period, &c.—Physical appearance.—Belts visible in large telescopes.—Position of its axis.—Attended by 4 Satellites.—Table of them.—Miscellaneous information concerning them.—Mass of Uranus.—Tables of Uranus.

ON March 13, 1781, whilst engaged in examining some small stars in the vicinity of H Geminorum, Sir W. Herschel noticed one which specially attracted his attention: and desirous of knowing more about it, he applied to his telescope higher magnifying powers, which (in contrast to their effect on fixed stars) he found increased the apparent diameter of the object under view considerably; this circumstance clearly proving its non-stellar character. Careful observations of position shewing it to be in motion at the rate of $2\frac{1}{2}''$ per hour, Herschel conjectured it to be a comet, and made an announcement to that effect to the Royal Society on April 26[a]. Four days after its first discovery it was observed by Maskelyne, then Astronomer Royal, who seems to have suspected at the time its planetary character, and in the course of the following 2 or 3 months it received the attention of all the leading observers of Europe. So soon as sufficient observations were accumulated, attempts were made by various calculators to assign parabolic elements for the orbit of the new body; though but little success attended their efforts. It was found that although a parabola might be obtained which would represent with tolerable accuracy a limited number

[a] *Phil. Trans.*, vol. lxxi. p. 492. 1781.

of observations, yet a larger range always revealed discrepancies which defied all endeavours to reconcile them with positions assigned on any parabolic hypothesis. The final determination was only arrived at step by step, and to Lexell must be ascribed the credit of first announcing, with any amount of authority, that the stranger revolved round the Sun in a nearly circular orbit, and that it was a planet and not a comet; though priority for this honour has been contested on behalf of Laplace.

The question of a name for the new planet was the next subject of debate. Herschel himself, in compliment to his sovereign and patron King George III, proposed that it should be called the *Georgium Sidus;* Lalande or, as some say, Laplace suggested the personal name of *Herschel;* but neither of these gave satisfaction to the Continental astronomers, who all declared for a mythological name of some kind. Prosperin considered *Neptune* appropriate, on the ground that Saturn would then be found between his two sons Jupiter and Neptune. Lichtenberg advanced the claims of *Astræa*, the goddess of justice, who fled to the confines of the system. Poinsinet thought that as Saturn and Jupiter, the fathers of the gods, were commemorated astronomically, it would be unpolite longer to exclude the mother, *Cybele.* Ultimately, however, Bode's *Uranus* prevailed over all others. A symbol was manufactured out of the initial of Herschel's surname, though in Germany, at the instigation of Köhler, one not differing much from that of Mars was adopted.

It soon became a matter of inquiry whether the new planet had ever been seen before, and here may be brought in a note of Arago's:—"If Herschel had directed his telescope to the constellation Gemini 11 days earlier (that is, on March 2 instead of March 13), the proper motion of Uranus would have escaped his observation, for on the 2nd the planet was in one of its stationary points. It will be seen by this remark on what may depend the greatest discoveries in astronomy [b]." A careful inspection of the

[b] On this remark of Arago's Holden says:—"This is an entire misconception, since the new planet was detected by its physical appearance and not by its motion. Does any one suppose that 'a new and singular star' like this would have been once viewed and then forgotten?" (*Life of W. Herschel*, p. 49.)

labours of former astronomers shewed that Uranus had been observed and recorded as a fixed star on 20 previous occasions: namely, by Flamsteed[c] in 1690, on Dec. 13; in 1712, on March 22; in 1715, on Feb. 21, 22, 27, and April 18 (all o.s.); by Bradley in 1748, on Oct. 21; in 1750, on Sept. 13, and in 1753, on Dec. 3; by Mayer in 1756, on Sept. 25; and by Le Monnier no less than 12 times—in 1750, on Oct. 14 and Dec. 3; in 1764, on Jan. 15; in 1768, on Dec. 27 and 30; in 1769, on Jan. 15, 16, 20, 21, 22 and 23; and in 1771, on Dec. 18. Had Le Monnier been a man of *order* and method it can scarcely be doubted that he would have anticipated Sir W. Herschel. Arago recollected to have been shewn by Bouvard one of Le Monnier's observations of the planet written on a paper bag, which originally contained hair-powder purchased at a perfumer's!

It will readily be understood that these early observations have been of great service to computers, inasmuch as they have been enabled to determine the elements of the planet's orbit with greater accuracy than they could otherwise have done simply by the aid of modern observations.

Uranus revolves round the Sun in 30,686·7 days, or rather more than 84 of our years, at a mean distance of 1,781,944,000 miles. The eccentricity of its orbit, which amounts to 0·04667 (rather less than that of Jupiter), may cause this to extend to 1,865,107,000 miles, or to fall to 1,698,781,000 miles. The apparent diameter of Uranus varies but slightly, as seen from the Earth; and its mean value is about 3·4″. (Seeliger, 3·82″: Millosevich, 3·96.″) The real diameter is about 31,000 miles. Sir W. Herschel saw the planet's outline strongly elliptical in 1792 and 1794, after having noted it to be round in 1782. Mädler at Dorpat in 1842 and 1843 measured the ellipticity to be $\frac{1}{10}$ or $\frac{1}{11}$. Arago however pointed out that a polar compression may exist but not always be visible, because a spheroid, when viewed in the direction of its axis, will necessarily present a truly

[c] Le Verrier, in his investigation of the theory of Uranus, rejected Flamsteed's observation of Feb. 22, 1715, and adopted another dated April 18, 1715. (Grant, *Hist. Phys. Ast.*, p. 165.)

circular outline, and this seems both the proper and a sufficient way of reconciling discordances on the subject which have been noted. Buffham on Jan. 25, 1870, thought that the ellipticity was "obvious[d]." Safarik after many observations between 1877 and 1883 considered the ellipticity to be "striking" and therefore in fact "considerable[e]." Prof. C. A. Young in 1883 measured the planet on several occasions and obtained an ellipticity of $\frac{1}{14}$. He considers that there can be no "reasonable doubt that the planet's disc is considerably flattened, its equator lying sensibly in the same plane with the satellite-orbits[f]." Schiaparelli too in 1884 obtained as he thought clear proofs of an ellipticity of $\frac{1}{13}$. But the measures of Seeliger at Munich and Millosevich at Rome in 1883 negative the idea.

It has been calculated that the amount of light received by Uranus from the Sun is equal to about the quantity which would be afforded by 300 Full Moons. The inhabitants of Uranus can see Saturn, and perhaps Jupiter, but none of the planets included within the orbit of the latter.

The physical appearance of Uranus may be disposed of in a few words. Its disc is commonly considered to be uniformly bright, bluish in tinge and without spots or belts. Yet both Lassell and Buffham have fancied they have seen traces of an equatorial belt and of inequalities of brilliancy on the planet's surface. Writing in 1883 Prof. C. A. Young says:—"Whenever the seeing was good 2 belts were always faintly but unmistakeably visible on each side of the equator much like the belts of Saturn. On one or two occasions other belts were suspected near the poles[g]." Schiaparelli too with an 8-inch refractor has detected faint spots and differences of colour on the disc of Uranus. The period of axial rotation is unknown, but analogy[h] leads us to suppose that it does not differ materially from that of Jupiter or Saturn. Buffham has ventured on a conjecture that some indications of

[d] *Month. Not.*, vol. xxxiii. p. 164. Jan. 1872.

[e] *Ast. Nach.*, vol. cv. No. 2505. Ap. 14, 1883. *Observatory*, vol. vi. p. 183. June, 1883.

[f] *Observatory*, vol. vi. p. 331. Nov. 1883.

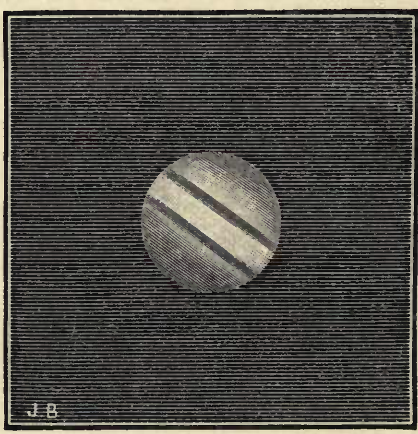
[g] *Observatory*, vol. vi. p. 331. Nov. 1883.

[h] See p. 68, *ante*.

spots seen by him imply a Rotation-period of 12^{h}. Sir W. Herschel once fancied he had seen traces of a ring or rings, but the observation was not confirmed by himself, nor has it been by others since. Uranus is just within the reach of the naked eye when in Opposition, and may be found without a telescope if the observer knows its precise place[i].

The direction of the axis of Uranus was supposed by Sir W. Herschel to be such that if prolonged it would at each end meet the planet's orbit. In consequence of this "the Sun turns in a spiral form round the whole planet, so that even the two poles sometimes have that luminary in their zenith[k]." Buffham very roughly makes the inclination of the axis 10°.

Fig. 122.



URANUS, 1884. (*Henry.*)

MM. Henry of Paris, in giving the accompanying sketch of Uranus as seen during 1884, say that they were able to detect constantly the existence of 2 belts, straight and parallel to one another, placed almost symmetrically on each side of the centre

[i] It is a somewhat singular fact that the Burmese mention eight planets: the Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, and *Rahù*, which latter is invisible. "An admirer of Oriental literature," says Buchanan, "would here discover the Georgium Sidus, and strip the illustrious Herschel of his recent honours."

[k] Sir W. Herschel, quoted in Smyth's *Cycle*, vol. i. p. 205.

THE SATELLITES OF URANUS.

	Order of Discovery.	Discoverer.		Mean Distance.		Sidereal Period.		Max. Elong.
				Radii of ♅	Miles.	d. h. m.	d.	″
1. Ariel	3	Lassell.	1847, Sept. 14	8·08	124,700	2 12 28	2·52	12
2. Umbriel ...	4	O. Struve.	1847, Oct. 8	11·27	173,900	4 3 27	4·14	15
3. Titania ...	1	Sir W. Herschel.	1787, Jan. 11	18·48	285,300	8 16 55	8·71	33
4. Oberon ...	2	,, ,,	,, ,,	24·72	381,600	13 11 6	13·46	44

Inclination ... ... 82° ±
Eccentricity ... ... Small.
Direction of motion ... ... Retrogarde.

of the planet. Between these 2 belts there was discernible a fairly bright zone, which seemingly corresponded to the equatorial region of the planet. The 2 poles were darkish; however, the upper pole in the engraving always appeared brighter than the lower. They also found as the result of a great number of measures that the direction of the belts did not coincide with the major axis of the apparent orbit of the satellites, but formed with it an angle of 40°, so that the position-angles observed were 56° for the belts and 16° for the major axis at the same epoch. MM. Henry suggest that in supposing, as it seems reasonable to do, that the belts of Uranus are parallel to its equator, and remembering that the latitude of the Earth above the plane of the orbit of the satellites when the observations were made was about 9°, there follows the result that the angle between the plane of the equator of Uranus and the plane of the orbits of the satellites is about 41°.

Uranus is attended by at least 4 satellites, 2 of which were discovered by Sir W. Herschel, and 2 by recent observers[1]. Such is their extreme minuteness that only the very largest telescopes will shew them, and for this reason our knowledge of them is very limited. Their chief peculiarity is the inclination of their orbits, which for *direct motion* amounts to ±98°; in other words, their Urani-centric motion is retrograde, the planes of the orbits lying nearly perpendicular (180°−98° = 82°) to the planet's ecliptic. The satellites, as Sir W. Herschel remarked, describe the Northern halves of their orbits, included between the ascending and descending nodes, in virtue of movements directed from E. to W.

Sir J. Herschel pointed out a test by which astronomers can ascertain whether their instruments are sufficiently powerful and their sight sufficiently delicate to undertake with any reasonable hope of success a search for these satellites. Between the stars β^1 and β^2 Capricorni, about the middle of the interval in

[1] Sir W. Herschel thought that he had discovered 6 satellites, which with the 2 discovered by Lassell and Struve would make a total of 8; but it is now accepted that Herschel's conclusions must have been based on some misapprehension: that is to say, that he mistook small stars for satellites.

R. A. and slightly to the N., there is a double star whose components are of mags. 16 and 17 [=13 and 13·6 of Argelander's magnitudes], and 3″ apart. No instrument incapable of shewing these two stars is suitable for observing the satellites of Uranus. In fact Sir John remarked that in comparison with the Uranian satellites these two stars are "splendid objects[m]."

Under these circumstances I shall be pardoned if I omit the details of the observations made by Sir William Herschel[n], his son[o], Lamont[p], O. Struve, and Lassell[q], more especially as the substance of them has been reproduced by Hind[r] and Arago[s]. Suffice it then to remark that, according to Lassell, Ariel and Umbriel are of nearly equal brightness, whilst Titania and Oberon are both much brighter than the 2 innermost satellites.

Under date of Jan. 11, 1853, Lassell said *he was fully persuaded that either Uranus has no other satellites than these* 4, *or if it has, they remain yet to be discovered;* but the assumption of 8 satellites was accepted by Arago and other influential astronomers. Lassell, writing in 1864 from Malta, on the occasion of his second visit, reiterated his former statement.

Fig. 123.

PLAN OF THE URANIAN SYSTEM.

It was found by Sir W. Herschel that the satellites disappeared when within a short distance ($\frac{1}{4}'$ or thereabouts) of the planet. This occurred whichever was the side of the planet on which the satellites happened to be, thus negativing the possibility of the phenomenon being due to an atmosphere on Uranus; and Sir William was led to assume that it was merely an effect of contrast—the comparatively great lustre of the planet overpowering the feeble glimmer of the satellites.

[m] Cited by Arago in *Pop. Ast.*, vol. ii. p. 628, Eng. ed., and by Smyth, *Celest. Cycle*, vol. ii. p. 475.

[n] *Phil. Trans.*, vol. lxxvii. p. 125, 1787; vol. lxxviii. p. 364, 1788; vol. lxxxviii. p. 47, 1798; vol. cv. p. 293, 1815.

[o] *Mem.* R.A.S., vol. viii. p. 1. 1835.

[p] *Mem.* R.A.S., vol. xi. p. 51. 1840.

[q] *Month. Not.*, vol. viii. p. 44, Jan. 1848; vol. xii. p. 152, March 1852; vol. xiii. p. 148, March 1853. *Mem.* R.A.S., vol. xxxvi. p. 34, 1867.

[r] *Sol. Syst.*, p. 121.

[s] *Pop. Ast.*, vol. ii. p. 623.

Hind, from Lassell's observations at Malta in 1852, has deduced the following elements :—

III. Titania.

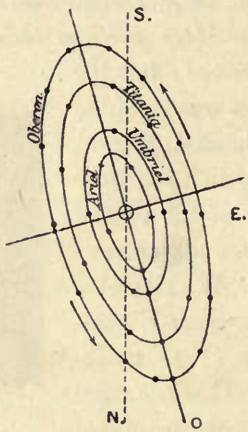
Radius of orbit at the mean distance of ♅ ...	33·88″ = 288,000 miles.
Longitude of ascending node	165° 25′
Inclination of orbit	100° 34′

IV. Oberon.

Radius of orbit at the mean distance of ♅ ...	45·20″ = 384,000 miles.
Longitude of ascending node	165° 28′
Inclination of orbit	100° 34′

From the distance of Titania the same computer obtained $\frac{1}{20505}$ as the mass of Uranus, Oberon indicating $\frac{1}{20642}$; results fairly

Fig. 124.



THE APPARENT ORBITS OF THE SATELLITES OF URANUS.

*** *The small circle represents the planet: the arrows, the direction in which the satellites move: each black dot, a day's interval reckoned from* O, *the epoch of the preceding Northern elongation.*

in accord with those of other observers, when the difficulties in obtaining data are considered. Encke's value was $\frac{1}{24905}$, Lamont's $\frac{1}{24605}$, Mädler's $\frac{1}{24516}$, A. Hall's $\frac{1}{22682}$, Adams's $\frac{1}{21000}$, Littrow's $\frac{1}{21000}$, and Bouvard's $\frac{1}{17918}$. Bouvard's value is now very generally rejected as excessive.

In computing the places of Uranus the Tables of A. Bouvard, published in 1821, were used up to quite a recent date. From what appears in the following chapter it will be evident that they were susceptible of material improvement, and they have now given place to those completed in 1872 by an American astronomer, Professor S. Newcomb, as to which it may be observed that they do not countenance the idea that there exists a trans-Neptunian planet. Newcomb has also framed Tables of the Satellites of Uranus[t].

[t] *Washington Obs.*, 1873, Appendix I.

CHAPTER XIV.

NEPTUNE[a]. ♆

Circumstances which led to its discovery.—Summary of the investigations of Adams and Le Verrier.—Telescopic labours of Challis and Galle.—The perturbations of Uranus by Neptune.—Statement of these perturbations by Adams.—Period, &c.—Attended by 1 *Satellite.—Elements of its orbit.—Mass of Neptune.—Observations by Lalande in* 1795.

MORE than half a century ago an able French astronomer, M. Alexis Bouvard, applied himself to the task of making a refined investigation of the motion of Uranus, in order to prepare Tables of the planet. He had at his disposal the various observations by Flamsteed and others, made prior to the direct optical discovery of Uranus, and those made by various astronomers subsequent to that event in 1781. In working these up he found himself able to assign an ellipse harmonising with the first series, and also one harmonising with the second; but by no possibility could he obtain an orbit reconcileable with both. As the less objectionable alternative, Bouvard decided to *reject* all the early observations and to confine his attention solely to those more recent[b]. In this way he produced, in 1821, Tables of the planet, fairly representing its motion in the heavens. This agreement, however, was not of long duration, and a few years

[a] Many French writers deal with the discovery of Neptune in a way that is not fair. Nothing is more common than to meet with a narrative of the incident either *without any mention, direct or indirect, of Mr. J. C. Adams,* or with some casual remark more or less implying that the English version is a trumped-up story due to national jealousy, and only intended to rob a deserving Frenchman of his share in the honours. Science ought to be international, and to rise above such petty insinuations.

[b] A memorable illustration of the folly and impolicy of rejecting *any* observation, merely because it opposes—or seems to oppose—a pre-conceived theory.

only elapsed before discordances appeared of too marked a character to be possibly due to any legitimate error in the Tables: constructed in the form in which they existed it was evident that they were defective in principle. Bouvard himself, who died in 1840, seems to have fancied that an exterior planet was alone the cause of the irregularities existing in the motion of Uranus, and the Rev. T. Hussey was led to assert this in decided terms in a letter to Airy in 1834. This conviction soon forced itself on astronomers [c], and amongst others on Valz, Mädler, and Bessel. Bessel, it would seem, entertained the intention of mathematically inquiring into the matter, but was prevented by an illness, which eventually proved fatal.

Mr. J. C. Adams, whilst a student at St. John's College, Cambridge, resolved to attack the question, and, as he found subsequently, entered a memorandum to this effect in his diary under the date of July 3, 1841, but it was not till January 1843 that he found himself with sufficient leisure to commence. He worked in retirement at the hypothesis of an exterior planet for 1¾ years, and in Oct. 1845 forwarded to Airy some provisional elements for one revolving round the Sun at such a distance and of such a mass as he thought would account for the observed perturbations of Uranus. This was virtually the solution of the problem in a theoretical point of view, and it is much to be regretted that neither the result nor any of the circumstances attending it were made public at the time.

In the summer of 1845, Le Verrier, of Paris, turned his attention to the anomalous movements of Uranus, and in the November of that year published his first memoir to prove that they did not depend solely on Jupiter and Saturn. In June 1846 the French astronomer published his second memoir to prove that an exterior planet was the cause of the residual disturbance. He

[c] As far back as October 25, 1800, Lalande and Burckhardt came to the conclusion that there existed an unseen planet beyond Uranus, and they occupied themselves in trying to discover its position. (*Year Book of Facts*, 1852, p. 282.) This statement is reputed to depend on a note to this effect found amongst Lalande's papers presented to the Academy of Sciences in 1852, but I am not acquainted with any other authority for it.

assigned elements for it, as Adams had done 8 months previously. A copy of the memoir reached Airy on June 23, and finding how closely in accord Le Verrier's hypothetical elements were with those of Adams, which were still in his possession, he was so impressed with the value of both, that on July 9 he wrote to Professor Challis of Cambridge to suggest the immediate employment of the large "Northumberland" telescope in a search for the planet. The proposal was agreed to, and on July 11 a systematic search was commenced. Challis, not being in possession of the Berlin Star Map of the particular locality in which it was supposed that the looked-for planet would be found, was forced to make observations for the formation of a map for himself; this was done, but much valuable time was occupied. When matters had reached this stage Sir J. Herschel seized an opportunity which happened to present itself, and thus addressed the British Association at Southampton on Sept. 10, 1846:—The past year has given us the new planet Astræa—"it has done more—it has given us the probable prospect of the discovery of another. We see it as Columbus saw America from the shores of Spain. Its movements have been felt, trembling along the far-reaching line of our analysis, with a certainty hardly inferior to that of ocular demonstration [d]." The Map was eventually got ready, but it was not till Sept. 29 that Professor Challis found an object whose appearance attracted his attention, and which was subsequently proved to be the new planet so anxiously sought. It was likewise ascertained afterwards that the planet had been observed for a star on Aug. 4 and 12, and that the supposed star of Aug. 12 was wanting in the zone of July 30. The non-discovery of its planetary nature on Aug. 12 was due to the fact of the comparisons not having been carried out quite soon enough; a pardonable though regrettable circumstance. It should be added that it was not until Oct. 1 that Challis heard of Galle's success on Sept. 23. (See *post.*)

In August Le Verrier published a third memoir, containing revised elements, in which particular attention was paid to the

[d] *Athenæum*, Oct. 3, 1846, p. 1019.

probable position of the planet in the heavens. On Sept. 23 a letter from him, containing a summary of the principal points of this memoir, was received by Encke of Berlin, whose co-operation in searching telescopically for the planet was requested. The Berlin observers had the good fortune to have just become possessed of Bremiker's Berlin Star Map for Hour XXI. of R.A., which embraces that part of the heavens in which both Adams and Le Verrier expected that the new planet would be found, and resort to this Map was suggested by D'Arrest, then a young student at the Berlin Observatory. On turning the telescope towards the assumed place, Galle, Encke's assistant, called out the visible stars one by one, and D'Arrest checked them by the Map. After a while Galle saw what seemed to be a star of the 8th magnitude, which was not laid down on the Map. Further observations on Sept. 24 placed it beyond a doubt that this 8th magnitude star was in reality the trans-Uranian planet; a discovery, the announcement of which, as may be well imagined, created the liveliest sensation. The French astronomers, with Arago at their head, disputed with unseemly violence the equal claims of Adams to participate with Le Verrier in the honours; but Airy, then Astronomer Royal, laid before the Royal Astronomical Society, on Nov. 13, such an overwhelming chain of evidence in favour of our distinguished countryman's exertions as seems to all impartial minds to have finally settled the question[e].

The intellectual grandeur of this discovery will be best appreciated, so far as a non-mathematical reader is concerned, by placing in juxtaposition the observed longitude of the new planet when telescopically discovered, and the computed longitudes of Adams and Le Verrier.

[e] The foregoing is a very bare outline of the case, which is a most interesting one. Grant (*Hist. Phys. Ast.*, p. 165 *et seq.*) gives full particulars; and reference may also be made to *Month. Not.*, vol. vii. p. 121, Nov. 1846; *Mem.* R.A.S., vol. xvi. p. 385, 1847; *Athenæum*, Oct. 3, 1846; Adm. Smyth's *Speculum Hartwellianum*, p. 405; and Sir J. Herschel's *Outlines of Ast.*, p. 533. The French case will be found stated in Arago's *Pop. Ast.*, vol. ii. p. 632; the English translator's notes to the passage are very appropriate. A very full statement of the facts of the case from a quite recent stand-point will be found in an obituary notice of Prof. Challis, in *Month. Not.*, vol. xliii. p. 160. Feb. 1883. D'Arrest's share in the work will be found explained in *Copernicus*, vol. ii. p. 63, 1882.

HELIOCENTRIC POSITIONS.

Observed by Galle	326° 52′
Computed by Adams	329° 19′
Computed by Le Verrier	326° 0′;

Adams Δ C – O = + 2° 27′
Le Verrier Δ C – O = – 0° 52′.

From this it will be seen that Le Verrier's computation proved to be slightly the more accurate of the two, a fact which in no respect militates against the equality of the merits of the two great mathematicians.

After considerable discussion *Neptune* was the name agreed upon for the new planet; Galle's suggestion of *Janus* being rejected as too significant.

Fig. 125.

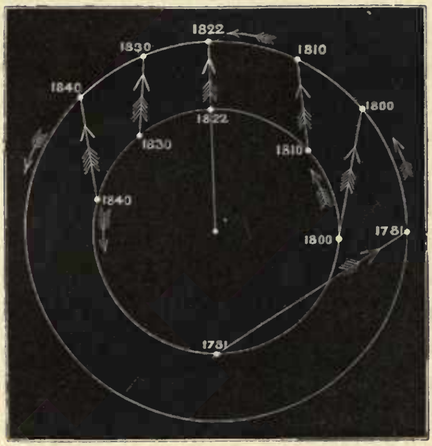


ILLUSTRATION OF THE PERTURBATION OF URANUS BY NEPTUNE.

"Such," in the words of Hind, "is a brief history of this most brilliant discovery, the grandest of which astronomy can boast, and one that is destined to a perpetual record in the annals of science—an astonishing proof of the power of the human intellect."

The accompanying diagram shews the paths of Uranus and Neptune from 1781 to 1840, and will help to illustrate the direction of the perturbing action of the latter planet on the former.

From 1781 to 1822 it will be evident, from the direction of the arrows, that Neptune tended to draw Uranus in advance of its place as computed independently of exterior perturbation.

In 1822 the two planets were in heliocentric conjunction, and the only effect of Neptune's influence was to draw Uranus farther from the Sun, without altering its longitude.

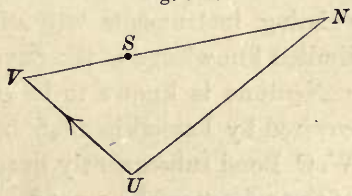
From 1822 to 1830 the effect of Neptune was to destroy the excess of longitude accumulated from 1781, and after 1830 the error in longitude changed its sign, and for some years subsequently Uranus was *retarded* by Neptune; having by 1846 fallen 128″ behind its place as predicted from Bouvard's tables.

Prof. Adams has kindly furnished me[f] with the following explanatory comment on the above diagram (Fig. 125):—

"The arrows rightly represent the direction of the force with which Neptune acts on Uranus taken singly, but the diagram does *not* represent the direction of the *disturbing* force which Neptune exerts on Uranus relatively to the Sun, and this latter force is what we must take into account in computing the planetary perturbations. To find this *disturbing* force, we must take the force of Neptune on the *Sun*, reverse its direction, and then compound this with the direct force of Neptune on Uranus.

"Thus if S denote the Sun, U Uranus, and N Neptune, the force of Neptune on Uranus will be in the direction UN and will be proportional to $\frac{1}{(UN)^2}$, and the force of Neptune on the Sun will be in the direction SN and will be proportional to $\frac{1}{(SN)^2}$. Hence if we produce NS, if necessary, to V and take $NV = \frac{(UN)^3}{(SN)^2}$, the reversed force of Neptune on the Sun will be represented by NV, provided the direct force of Neptune on Uranus be represented by UN. Hence the *disturbing* force of Neptune on Uranus relatively to the Sun will be represented on the same scale in magnitude and direction by UV, the direction being indicated by the arrow in the figure, and the magnitude of the disturbing force being proportional to $\frac{UV}{(UN)^3}$.

Fig. 126.



THE PERTURBATION OF URANUS BY NEPTUNE.

"It is not possible to state the effect of Neptune's action on the motion of Uranus in such simple terms as you have attempted to do, since it is necessary to take into account the action of Neptune in order to find the correct elements of the orbit of Uranus, and consequently the corrections of the assumed elements must be taken as additional unknown quantities which must be determined simultaneously with the perturbations depending on Neptune."

Neptune revolves round the Sun in 60,126 days, or 164·6 years, at a mean distance of 2,791,750,000 miles, which an eccentricity of 0·0087 will increase to 2,816,094,000 miles, or diminish to 2,767,406,000 miles. The apparent diameter of Neptune only varies between 2·6″ and 2·8″. Its true diameter is about 37,200

[f] Private letter dated Cambridge, May 8, 1884.

miles—a diameter somewhat greater than that of Uranus. No polar compression is perceptible.

Neptune is destitute of visible spots and belts, and at present the period of its axial rotation is unknown. But it deserves to be stated that on 14 nights in November and December 1883 Maxwell Hall in Jamaica observed periodical variations in the light of Neptune which he thought might have been due to an axial rotation occupying $7^h\ 55^m\ 12^s$. He arrived at this result after finding that the planet's light seemed to change from a maximum star mag. of 7½ to a minimum of 8½ in a period of something under 4 hours[g]. Lassell, Challis, and Bond at various times suspected the existence of a ring but nothing certain is known on the subject. It would be very desirable to have a large reflector like Lord Rosse's, or a large refractor like those at the Lick and Vienna Observatories, devoted to a series of observations of this planet and Uranus, for it is nearly certain that no other existing instruments will add much to our present extremely limited knowledge of the physical appearance of these planets.

Neptune is known to be attended by only one satellite, discovered by Lassell in 1846, but both that observer and the late W. C. Bond subsequently imagined that they had obtained traces of the existence of a second.

The following table furnishes all the information we at present possess about Lassell's confirmed satellite :—

THE SATELLITE OF NEPTUNE.

	Discoverer.	Mean Distance.		Sidereal Period.		Apparent Star magnitude.	Max. Elong.
		Radii of ♆ = 1.	Miles.	d. h. m.	d.		″
I	Lassell. 1846, Oct. 10	12·00	223,000	5 21 3	5·88	14	18

Changes appear to be in progress in the plane of the orbit of this satellite the precise nature of which await further observation and explanation[h].

[g] *Month. Not.*, vol. xliv. p. 257. March 1884.

[h] *Observatory*, vol. xi. p. 446. Dec. 1888.

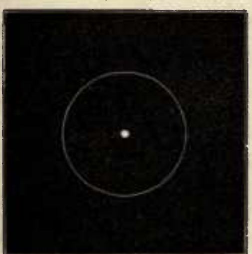
Hind gives the following elements[1] :—

Epoch 1852, Nov. 0·0 G. M. T.

	°	′
Mean anomaly	243	32
Peri-neptunium	177	30
☊	175	40
ι	151	0
Eccentricity	6	5 = 0·1059748
Period	5·8769^{d}.	

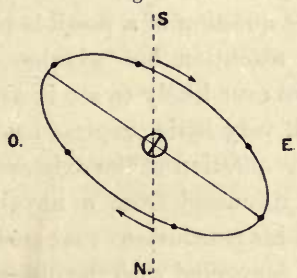
The elements are calculated for *direct* motion; accordingly it will be noticed that the actual Neptunicentric motion of the satellite is *retrograde*—a circumstance which, except in the case of the Uranian satellites, is without parallel in the solar system as regards either planets or satellites; though there are many *retrograde* comets.

Fig. 127.



PLAN OF THE ORBIT OF THE SATELLITE OF NEPTUNE.

Fig. 128.



ORBIT OF THE SATELLITE OF NEPTUNE.

The mass of Neptune has been variously estimated at $\frac{1}{20039}$ by Safford; at $\frac{1}{19400}$ by Bond; at $\frac{1}{19092}$ by A. Hall; at $\frac{1}{19000}$ by Littrow; at $\frac{1}{18780}$ by Peirce; at $\frac{1}{18279}$ by Holden; at $\frac{1}{17900}$ by Hind, from a combination of early measures; at $\frac{1}{17850}$ by Lassell and Marth; at $\frac{1}{17135}$ by Hind from Lassell's Malta measures; at $\frac{1}{14494}$ by O. Struve; and at $\frac{1}{14455}$ by Mädler.

The only known observations of Neptune made previously to its discovery in 1846 are two by Lalande, dated May 8 and 10, 1795, and one by Lamont of Oct. 25, 1845. Two by the same

[1] *Month. Not.*, vol. xv. p. 47. Dec. 1854. For some of Lassell's observations see vol. xii. p. 155, March 1852, and vol. xiii. p. 37, Dec. 1852.

astronomer on Sept. 7 and 11, 1846, were probably due to Le Verrier's announcement made just before, and therefore are not entitled to be regarded as casual ones.

Owing to its immense distance from the Sun, only Saturn and Uranus can be seen from Neptune. Though deprived of a view of the principal members of the solar system, the Neptunian astronomers, if there be any, are well circumstanced for making observations on stellar parallax; seeing that they are in possession of a base-line of 5,584,000,000 miles, or one more than 30 times the length of that to which we are restricted.

Our present knowledge of the movements of Neptune is derived from the investigations of the late S. C. Walker, of Philadelphia, U.S., and from the Tables of M. Kowalski and Professor S. Newcomb. Newcomb has also framed Tables of the satellite of Neptune [k].

The question of a possible planet beyond Neptune has received some attention, but whether such a planet exists, and whether we are ever likely to see it, are problems towards the solution of which very little progress has yet been made [l].

The question of the existence of a Trans-Neptunian planet has been discussed from a novel stand-point by Flammarion. He bases his conclusions that such a planet does exist on considerations connected with the grouping of the comets whose periodicity is open to no doubt. He seeks to show that all the 4 major planets beyond Mars have seemingly a group of comets associated with them in some way; and that beyond Neptune there is a group of comets to influence which no planet is yet known to exist. Hence his conclusion that such a planet does exist but that we have not yet seen it. This in brief is Flammarion's argument, which is worked out with considerable ingenuity and care, but with materials borrowed, without acknowledgement, from others [m].

[k] *Washington Obs.*, 1873, Appendix I.

[l] See Prof. G. Forbes's *Comets and Ultra-Neptunian Planets;* also a paper by D. P. Todd of the *American Nautical Almanac* Office entitled "*Preliminary account of a speculative and practical search for a Trans-Neptunian planet,*" 8vo., Washington, U.S., 1880; *Ast. Nach.*, vol. cxiii. No. 2698, Dec. 21, 1885. Todd's search extended over 4 months during the winter of 1877–8.

[m] *L'Astronomie,* vol. iii. p. 81. March 1884. Forbes seems to have been the originator of this theory.

BOOK II.

ECLIPSES[a] AND ASSOCIATED PHENOMENA.

CHAPTER I.

GENERAL OUTLINES.

Definitions.—Position of the Moon's orbit in relation to the Earth's orbit.—Consequences resulting from their being inclined to each other.—Retrograde motion of the nodes of the Moon's orbit.—Coincidence of 223 *synodical periods with* 19 *synodical revolutions of the node.—Known as the "Saros."—Statement of Diogenes Laërtius.—Illustration of the use of the Saros.—Number of Eclipses which can occur.—Solar Eclipses more frequent than Lunar ones.—Duration of Annular and Total Eclipses of the Sun.*

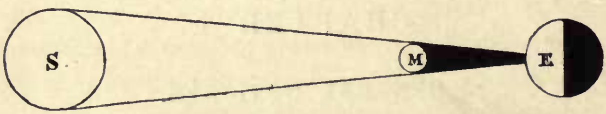
THE phenomena which are about to be described are those which result from the interposition of some one celestial body between 2 other bodies, the Earth in any case being one of the 3. We know well that inasmuch as most of the heavenly bodies are constantly in motion, the direction of lines drawn from one to another must vary from time to time; and it must occasionally happen that 3 will come into a right line. "When one of the extremes of the series of 3 bodies which thus assume a common direction is the Sun, the intermediate body deprives the other extreme body,

[a] The portions of this Book which relate to Eclipses of the Sun have been revised and much extended for this edition by my friend Mr. A. C. Ranyard, *facile princeps* in this department of Astronomy.

either wholly or partially, of the illumination which it habitually receives. When one of the extremes is the Earth, the intermediate body intercepts, wholly or partially, the other extreme body from the view of observers situate at places on the Earth which are in the common line of direction, and the intermediate body is seen to pass over the other extreme body, as it enters upon or leaves the common line of direction. The phenomena resulting from such contingencies of position and direction are variously denominated *Eclipses*, *Transits*, and *Occultations*, according to the relative apparent magnitudes of the interposing and obscured bodies, and according to the circumstances which attend them."

We will proceed to consider these several phenomena in detail beginning with Eclipses.

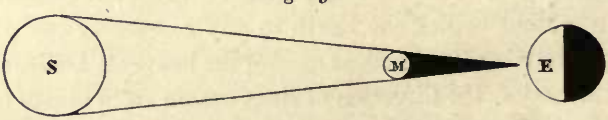
Fig. 129.



THEORY OF A TOTAL ECLIPSE OF THE SUN.

It must be premised that the Moon's orbit does not lie in exactly the same plane as the Earth's, but is inclined thereto at an angle which varies between 5° 20′ 6″ and 4° 57′ 22″, and for which 5° 8′ 45″ may be taken as the mean value. The two points where its path intersects the ecliptic are called the *Nodes*, and the imaginary line joining these points is termed the *Line of Nodes*.

Fig. 130.



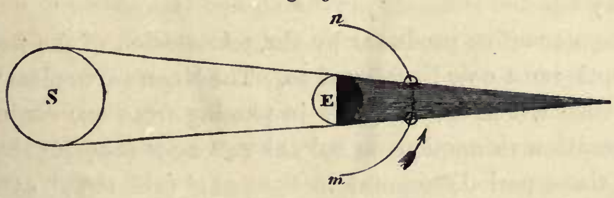
THEORY OF AN ANNULAR ECLIPSE OF THE SUN.

When the Moon is crossing the ecliptic from South to North, it is passing its *Ascending Node* (☊), the opposite point of its orbit being its *Descending Node* (☋). If the Moon should happen to pass through either node at or near the time of conjunction, or New Moon, it will necessarily come between the Earth and the

Sun, and the 3 bodies will be in the same straight line; it will therefore follow that to certain parts of the Earth the Sun's disc will be obscured, wholly or partially as the case may be: this is an *Eclipse of the Sun.* In the figures above, S represents the Sun, E the Earth, and M the Moon. In a total solar eclipse the Moon's shadow reaches to and beyond the Earth's surface, the Moon being then at or near its minimum distance from the Earth ("perigee"). In an annular eclipse the Moon's shadow falls short of the Earth, the Moon being then at or near its maximum distance from the Earth ("apogee").

The Earth and the Moon, being opaque bodies, must cast shadows into space; though of course, owing to the larger size of the Earth, its shadow is much the larger of the two. If the Moon should happen to pass through either node at or near the time of Opposition, or Full Moon, it will be again, as before, in the same straight line with the Earth and the Sun; but the Moon will be involved in the shadow of the Earth, and therefore will be deprived of the Sun's light; this causes an *Eclipse of the Moon.*

Fig. 131.



THEORY OF AN ECLIPSE OF THE MOON.

In Fig. 131, S represents the Sun, E the Earth, and *m n* the orbit of the Moon: that the Moon becomes involved in the Earth's shadow in passing from *m* to *n* is obvious.

If the orbits of the Earth and the Moon were in the same plane, an eclipse would happen at every conjunction and opposition, or about 25 times a year; but as such is not the case, eclipses are of less frequent occurrence. According to trustworthy investigations, in order that an eclipse of the Sun may take place, the greatest possible distance of the Sun or Moon from the *true place* of the nodes of the Moon's orbit is 18° 36′, whilst the latitude of the Moon must not exceed 1° 34′ 52″. If, however, the distance be less than 15° 19′ 30″, and the latitude less than 1° 23′ 15″, an eclipse must take place, though between these limits the occurrence of the eclipse at any station is doubtful, and depends upon the horizontal parallaxes and apparent semi-diameters of the two bodies at the moment of conjunction. In order that a lunar eclipse may take place, the remark just made will equally hold good, except that 12° 24′, 9° 23′, 63′ 45″ and 51′ 57″, must be substituted for the quantities given above.

The nodes of the Moon's orbit are not stationary, but have a daily retrograde motion of 3′ 10·64″ or an annual one of 19° 20′ 19·7″, so that a complete revolution round the ecliptic is accomplished in $18^y\ 218^d\ 21^h\ 22^m\ 46^s$ nearly. The Moon performs a revolution with respect to the node in $27^d\ 5^h\ 5^m\ 36^s$ ($27{\cdot}21222222^d$). This is termed a "*nodical* revolution of the Moon [b]," and must not be confounded with the "*synodical* revolution of the Moon." It is shorter than the latter, because the retrograde motion of the node upon the ecliptic brings the Moon into contact with it before she comes again into Conjunction or Opposition as the case may be.

A singular effect produced by the retrocession of the nodes on the ecliptic must now be referred to. The Moon's synodical period, or the time which she occupies in passing from one conjunction or Opposition to another, is $29^d\ 12^h\ 44^m\ 2{\cdot}87^s$ ($29{\cdot}5305887215^d$); 223 of these periods amount to $6585{\cdot}321^d$ ($18^y\ 10^d\ 7^h\ 43^m$); but 19 revolutions of the Sun with respect to the lunar node [c] (each of $346{\cdot}6201^d$) are completed in $6585{\cdot}782^d$: the near coincidence of these two periods produces this obvious result; that eclipses

[b] Sometimes the *Draconic Period.*

[c] If the lunar nodes were immoveable the Sun would return to the same positions with respect to them every terrestrial tropical year; but this luni-nodical revolution of the Sun, if such an expression may be used, is less than the tropical year for the same reason that the *nodical* lunar month is less than the *synodical* one, the node receding to meet the Sun instead of remaining stationary. Since the lunar nodes travel at only 3′ 10″ per day, compared with the Sun's ecliptic motion of 59′ 9″, it follows that the nodes require $18{\cdot}6^d$ to get over the angular distance which the Sun does in 1^d. Deducting then $18{\cdot}6^d$ from $365{\cdot}242^d$ (the mean solar year), we get $346{\cdot}642^d$, as above, for the period of the Sun's return to the same lunar nodes.

recur in almost, though not quite, the same regular order after the completion of 19 synodical revolutions of the Moon's node. The difference between the two periods is $0{\cdot}461^{d}$, or $10^{h}\ 49{\cdot}6^{m}$; during which time the Sun describes an arc of 28′ 6″ relative to the lunar node.

These coincidences will be better brought out by the figures being placed in column, thus:—

	d.		d.
242 Draconic Periods	(27·21222 × 242)	=	6585·35777.
223 Lunations	(29·53058 × 223)	=	6585·31934.
19 Returns of Sun to Moon's Node	(346·6201 × 19)	=	6585·7819.

Some trifling discrepancies in the last column compared with the results given above are due to different decimals having been employed in the multiplication.

It was probably a knowledge of these facts which enabled the ancient astronomers to predict the occurrence of great eclipses, since it is quite certain that they did so in more than one instance before the nature of eclipses was fully understood. This cycle was known to the Chaldæans as the *Saros*[d]. Diogenes Laërtius records 373 solar and 832 lunar eclipses observed in Egypt; and although his testimony is, generally, of no great value, yet it is very singular that this is just the proportion of solar and lunar eclipses visible above a given horizon within a certain period of time (1200–1300 years)—a coincidence which cannot be accidental[e].

From what I have just said it might be imagined that a correct list of eclipses for 18·03 years would be sufficient for all purposes of calculation; and that the occurrence of an eclipse might be ascertained in advance at any distance of time by the simple process of adding so many ecliptic periods as were found

[d] See *Eng. Cycl.*, art. *Saros*. It has been stated that the Chaldæans used a triple *Saros* of $54^{y}\ 31^{d}$ as more correct for purpose of prediction than a single one. For a good deal of interesting information respecting matters incidentally connected with the *Saros*, see Newcomb and Holden's *Astronomy for Schools and Colleges*, New York, 1879, pp. 180–4, and Newcomb's *Popular Astronomy*, Lond. ed., p. 29. The German translation of this latter work contains still further and better particulars. (Trans. by Engelmann, p. 26.)

[e] *Hist. of Ast.*, L.U.K., p. 15.

requisite. This would be nearly correct if an eclipse appeared under precisely the same circumstances as the one in the preceding or following period corresponding to it: but such is not the case[f]. An eclipse of the Moon, which in the year 565 A.D. was of 6 digits[g], was in the year 583 of 7 digits, and in 601 of nearly 8. In 908 the eclipse became total, and it remained so for about 12 periods, or until the year 1088: this eclipse continued to diminish until the commencement of the 15th century, when it totally disappeared in the year 1413. In a similar manner an eclipse of the Sun, which appeared at the North Pole in June 1295, became more southerly at each period. On Aug. 27, 1367, it made its first appearance in the north of Europe; in 1439 it was visible all over Europe; at its 19th appearance, in 1601, it was central in London; on May 5, 1818, it was visible at London, and was again nearly central at that place on May 15, 1836. At its 39th appearance, August 10, 1980, the Moon's shadow will have passed the equator, and, as the eclipse will take place near midnight, it will be invisible in Europe, Africa, and Asia. At every subsequent period the eclipse will go more and more towards the south, until, finally, at its 78th appearance on Sept. 30, 2665, it will go off at the South Pole of the Earth, and disappear altogether. The time required for a lunar eclipse to go through all its Saros changes (so to speak) is 865 years. A similar series of solar eclipses will last much longer, or about 1200 years.

In the 18-year eclipse period, there usually happen 70 eclipses, of which 41 are solar and 29 are lunar. In any one year the

[f] Halley found that if this period were added to the middle of any eclipse, the corresponding one might be predicted to within $1^h\ 30^m$. According as 4 or 5 leap-years intervene, the period of the Saros will be $18^y\ 10^d$ &c. or $18^y\ 11^d$ &c.

[g] A digit is the $\frac{1}{12}$ part of the diameter of the Sun or Moon; and of course an eclipse of 6 digits will be understood to be one in which $\frac{1}{2}$ the disc of the luminary is hidden. In the case of a lunar eclipse, when the magnitude is said to exceed 12 digits, it means that the Earth's shadow extends itself so many digits beyond the Moon's contour. The *Companion to the Almanac* for 1832 contains (p. 8) some useful memoranda about digits, and a description of the path of the central line at different periods of the year. The older astronomers treated the digit as a measure of *surface* and indicated by its use that $\frac{1}{12}$ of the visible *area* of the Sun, or Moon, was obscured, not $\frac{1}{12}$ of its diameter; but in more recent times the word was used as stated at the beginning of this note. It is now however quite obsolete in both senses, and the magnitude of every eclipse is expressed decimally.

greatest number that can occur is 7, and the least 2: in the former case 5 of them *may* be solar, and 2 lunar; in the latter both *must* be solar. Under no circumstances can there be more than 3 lunar eclipses in 1 year, and in some years there are none at all. Though eclipses of the Sun are more numerous than those of the Moon in the proportion of 41 to 29 (say of 3 to 2), yet at any given place more lunar eclipses are visible than solar: because, whilst the former are visible over an entire hemisphere, the area of the Earth over which the latter are visible is in the case of total or annular eclipses a narrow strip, which cannot exceed 180 and is seldom more than 140 miles or so in breadth. In the case of partial eclipses of the Sun however the range of visibility is, it is true, much wider; for at every point of the Earth immersed in the penumbra more or less of the eclipse will be seen.

In a solar eclipse the Moon's shadow traverses the Earth at the rate of 1830 miles an hour, or rather more than half a mile per second. This corresponds to 30½ miles per minute; Lalande's result is equivalent to 33·1 miles.

Du Séjour found that, counting from first to last, a solar eclipse at the equator may last $4^h\ 29^m\ 44^s$, and that at the latitude of *Paris* the maximum period is $3^h\ 26^m\ 22^s$, but that the interval of time during which the Sun will be centrally eclipsed is very small. The duration of the total obscuration is greatest when the Moon is in perigee and the Sun in apogee; for the apparent diameter of the Moon being then the greatest possible, while that of the Sun is the least possible, the excess of the former over the latter, upon which the totality depends, is at a maximum. Now the perigean diameter of the Moon $= 33'\ 31''$; the apogean diameter of the Sun $= 31'\ 30''$.

$$\therefore \quad \Delta = 33'\ 31'' - 31'\ 30'' = 2'\ 1''.$$

This then is theoretically the arc which has to be described by the Moon during the greatest possible continuance of the total phase, but in reality the ultimate result is complicated by the Sun's apparent motion Eastward and the Earth's axial rotation in the same direction. However, taking into consideration the rapid motion of the Moon, it will be readily understood that, under the most favourable circumstances, the Sun cannot remain totally eclipsed for more than a few minutes.

The duration of the obscuration in a total eclipse of the Sun varies, *cæteris paribus*, with the latitude of the place of observation, and is greatest under the equator. Du Séjour[h] found that, under the most favourable circumstances, the greatest possible duration of the total phase at the equator was $7^m\ 58^s$, and that at the latitude of *Paris* it was $6^m\ 10^s$.

The duration of an annular eclipse is greatest when the Moon is in apogee and the Sun in perigee, for then the apparent diameter of the Sun is the greatest, whilst that of the Moon is the least possible, and consequently the excess of the former over the latter (upon which the annulus depends) is then at a maximum.

The perigean diameter of the Sun $= 32'\ 35''$. The apogean diameter of the Moon $= 29'\ 22''$.

$$\therefore \quad \Delta = 32'\ 35'' - 29'\ 22'' = 3'\ 13''.$$

This then is theoretically the arc which has to be described by the Moon during the greatest possible continuance of the annular phase, but, as before, some qualification is requisite in dealing with the facts which present themselves. Du Séjour found that under the most favourable circumstances the greatest possible duration of the annular phase at the equator[i] was $12^m\ 24^s$, and that at the latitude of *Paris*[k] it was $9^m\ 56^s$.

It may be desirable briefly to point out the reasons why the greatest possible duration of an annular eclipse exceeds that of a total one. They are 2 in number: 1st. Because the excess of the perigean diameter of the Sun over the apogean diameter of the Moon $(= 3'\ 13'')$ is greater than the excess of the perigean diameter of the Moon over the apogean diameter of the Sun $(= 2'\ 1'')$. 2nd. Because the motion of the Moon in apogee is much slower than it is in perigee.

From the above remarks it will be readily understood that though so many solar eclipses happen from time to time, yet

[h] *Mém. Acad. des Sciences*, 1777, p. 318.
[i] *Ibid.*, p. 317. [k] *Ibid.*, p. 316.

the occurrence of an annular or total one at any particular locality is a very rare phenomenon. Thus, according to Halley[l], no total eclipse had been observed at London between March 20, 1140, and April 22, 1715 (O. S.), though during that interval the shadow of the Moon had frequently passed over other parts of Great Britain[m].

The calculation of eclipses is a matter of considerable complexity. A paper by Woolhouse, in the supplement to the *Nautical Almanac* for 1836, and the chapters in Loomis's well-known work[n], may be named as the best guides in our language[o]. Much interesting historical matter concerning eclipses will be found in the Rev. S. J. Johnson's *Eclipses, Past and Present.*

[l] *Phil. Trans.*, vol. xxix. p. 245. 1715.

[m] It may here be noted that, according to recent investigations by Hind, the Total solar eclipse of Feb. 3, 1916, will not be visible as such in England, though a statement to that effect may occasionally be met with. On June 30, 1954, occurs the next Total eclipse which will be visible in Great Britain; this will be seen at the northernmost of the Shetland Isles. The eclipse of Aug. 11, 1999, is the next that will be visible as a Total one in England itself. The line of totality will pass across Cornwall and Devonshire. Hind, in connection with the calculations from which these particulars were derived, ascertained that the eclipse of 1140 was not centrally visible in London. The line of totality crossed the Midland Counties, and did not approach London nearer than Northamptonshire. (See letters by Hind in *Ast. Reg.*, vol. vii. p. 87, April 1869, and vol. ix. p. 209, Sept. 1871; also a paper by the Rev. S. J. Johnson in *Month. Not.*, vol. xxxii. p. 332. 1872.)

[n] *Practical Astronomy*, pp. 226-90.

[o] It is recorded by Rittenhouse that in his early days he calculated eclipses on his plough-handle. For a brief sketch of the career of this 'self-made' man (a pioneer of astronomy in America) see Sid. Mess., vol. vii. p. 433, Dec. 1888.

CHAPTER II.

ECLIPSES OF THE SUN.

Grandeur of a Total Eclipse of the Sun.—How regarded in ancient times.—Effects of the progress of Science.—Indian Customs.—Effect on Birds at Berlin in 1887.—Solar Eclipses may be Partial, Annular, or Total.—Chief phenomena seen in connexion with Total Eclipses.—Change in the colour of the sky.—The obscurity which prevails.—Effect noticed by Piola.—Physical explanation.—Baily's Beads.—Extract from Baily's original memoir.—Probably due to irradiation.—Supposed to have been first noticed by Halley in 1715.—His description.—The Corona.—Hypothesis advanced to explain its origin.—Probably caused by an atmosphere around the Sun.—Remarks by Grant.—First alluded to by Philostratus.—Then by Plutarch.—Corona visible during Annular Eclipses.—The Red Flames.—Remarks by Dawes.—Physical cause unknown.—First mentioned by Stannyan.—Note by Flamsteed.—Observations of Vassenius.—Aspect presented by the Moon.—Remarks by Arago.

A TOTAL eclipse of the Sun is a most imposing spectacle, especially when viewed from the summit of a lofty mountain, and the moon's shadow is seen sweeping upward from the horizon towards the observer with a velocity which has been described as perfectly frightful. Professor Forbes, who observed the total eclipse of 1842 from the Observatory of Turin, was so confounded by the frightful velocity with which the shadow swept over the earth from the distant Alps towards him that he felt as if the great building on which he was standing was commencing to fall over in the direction of the coming darkness. Words can but inadequately describe the grandeur and magnificence of the scene. On all sides indications are afforded that something unusual is taking place. At the moment of totality the darkness is usually so intense that the brighter planets and stars of the 1st and 2nd magnitude are seen, birds go to roost, flowers close, and the face of nature assumes an unearthly cadaverous hue; while not the least striking thing is the sudden gust of wind which frequently sweeps over the country with some violence at the commencement of totality; sometimes a considerable fall takes place in the temperature of the atmosphere as the time of the greatest obscuration draws near.

"During the early history of mankind, a total eclipse of the Sun was invariably regarded with a feeling of indescribable terror, as an indication of the anger of the offended Deity, or the presage of some impending calamity; and various instances are on record of the (supposed) extraordinary effects produced by so unusual an event. In a more advanced state of society, when Science had begun to diffuse her genial influence over the human mind, these vain apprehensions gave place to juster and more ennobling views of nature; and eclipses generally came to be looked upon as necessary consequences flowing from the uniform operation of fixed laws, and differing from the ordinary phenomena of nature only in their less frequent occurrence. To astronomers they have in all ages proved valuable in the highest degree, as tests of great delicacy for ascertaining the accuracy of their calculations relative to the place of the Moon, and hence deducing a further improvement of the intricate theory of her movements. In modern times, when the physical constitution of the celestial bodies has attracted the attention of many eminent astronomers, observations of eclipses have disclosed several interesting facts, which have thrown considerable light on some important points of inquiry respecting the Sun and Moon [a]."

Among the Hindus a singular custom exists [b]. When during

[a] Grant, *Hist. Phys. Ast.*, p. 359. The truth of the last sentence of this extract is now more striking than it was in 1852.

[b] In my first edition I wrote "is said to exist," but the following paragraph, cut from a newspaper in 1868, and relating to the great eclipse of Aug. 18, 1868, will shew that the present reading of the text is preferable:—"Tuesday was a general holiday, and the natives signified the swallowing of the sun by a demon by the usual drumming, shrieking, and blowing of shells, with offerings of rice." Nor is this an isolated incident. The following account was written of the eclipse of the Sun of July 29, 1878, by a resident at Fort Sill, Indian Territory, to Mr. Fox, Ex-Mayor of Philadelphia, U.S., who allowed its publication in the

a solar eclipse the black disc of our satellite is seen advancing over the Sun, the natives believe that the jaws of some monster are gradually eating it up. They then commence beating gongs, and rending the air with the most discordant screams of terror and shouts of vengeance. For a time their efforts are productive of no good result—the eclipse still progresses. At length, however, the terrific uproar has the desired effect on the voracious monster; it appears to pause, and then, like a fish that has nearly swallowed a bait and then rejects it, it gradually disgorges the fiery mouthful. When the Sun is quite clear of the great dragon's mouth, a shout of joy is raised, and the poor natives disperse, extremely self-satisfied on account of their having (as they suppose) so successfully relieved their deity from his late perils. For us times have now happily altered. *We* do not look on a total eclipse of the Sun as a dire calamity, but merely as one of the ordinary effects resulting from the due working of those laws by which the Supreme Being wills to govern the universe.

The Eclipse of Aug. 19, 1887, deficient though it was in Astronomical results, yielded some rather interesting observations with respect to the effect of the eclipse on birds. In N. E. Germany, foresters stated that the birds, which had already begun to sing before the eclipse took place, became of a sudden quite silent, and

Philadelphia Inquirer:—"On Monday last we were permitted to see the eclipse of the sun in a beautiful bright sky. Not a cloud was visible. We had made ample preparation, laying in a stock of smoked glass several days in advance. It was the grandest sight I ever beheld, but it frightened the Indians badly. Some of them threw themselves upon their knees and invoked the Divine blessing; others flung themselves flat on the ground face downward; others cried and yelled in frantic excitement and terror. Finally one old fellow stepped from the door of his lodge, pistol in hand, and fixing his eyes on the darkened sun mumbled a few unintelligible words, and raising his arm, took direct aim at the luminary, fired off his pistol, and after throwing his arms about his head in a series of extraordinary gesticulations, retreated to his own quarters. As it happened that very instant was the conclusion of totality. The Indians beheld the glorious orb of day once more peep forth, and it was unanimously voted that the timely discharge of that pistol was the only thing that drove away the shadow and saved them from the public inconvenience that would have certainly resulted from the entire extinction of the sun."

See for recent instances of popular excitement at eclipses, 2 engravings and narratives in *L'Astronomie*, vol. vi. p. 248, July 1887, and relating to the eclipses of Dec. 16, 1880, and March 1, 1877, as seen at Tashkend and Laos (Indo-China) respectively.

showed signs of disquiet when darkness set in. Herds of deer ran about in alarm, as did the small four-footed game. In Berlin a scientific man arranged for observations to be made by bird-dealers of the conduct of their feathered stock. The results were found to vary considerably. In some cases the birds shewed sudden sleepiness, even though they had sung before the eclipse took place. In other cases great uneasiness and fright were observed. Parrots shewed far more susceptibility than canaries, becoming totally silent during the eclipse, and only returning very slowly to their usual state.

An eclipse of the Sun may be either *partial*, *annular*, or *total*: it is partial when only a portion of the Moon's disc intervenes between the Sun and the observer on the Earth; annular, when the Moon's apparent diameter is less than the Sun's, so that when the former is projected on the latter it is not sufficiently large completely to cover it,—an annulus, or ring of the Sun, being left unobscured; and total when the Moon's apparent diameter is greater than that of the Sun, which is, therefore, wholly obscured. In an annular eclipse, when the centre of the Sun and Moon exactly coincide, it is said to be *central and annular*—the Sun appearing, for a very short time, as a brilliant ring of light around the dark body of the Moon.

I shall now proceed to describe the principal phenomena which are usually witnessed in connexion with solar eclipses.

Not the least remarkable is the almost invariable change of colour which the sky undergoes. Halley, in his account of the eclipse of 1715, says: "When the eclipse was about 10 digits (that is, when about $\frac{5}{6}$ of the solar diameter was immersed), the face and colour of the sky began to change from a perfect serene azure blue to a more dusky livid colour, intermixed with a tinge of purple, and grew darker and darker till the total immersion of the Sun [c]."

At the moment of totality the suddenly altered conditions of illumination give rise to a further change of colour which is so

[c] *Phil. Trans.*, vol. xxix. p. 247. 1715. Arago gives an elaborate explanation of this. *Pop. Ast.*, vol. ii. p. 358, Eng. ed.

striking that few observers fail to notice it. The lower part of the atmosphere within the Moon's shadow is illuminated by light from the horizon which has passed through many miles of atmosphere near to the earth's surface and has therefore lost much from the violet end of the spectrum. The particles floating in the lower atmosphere therefore disperse a ruddy light which projected upon the deep blue of the upper atmosphere gives rise to a combination of colour which may well be described as purple or violet. Weeden, who observed the total eclipse of 1860 near Miranda in Spain, says that the heavens during totality seemed like a dark purple canopy, hanging low down as it were, in the shape of a watch-glass, and covering the earth, excepting in a regular belt near the horizon, where the illuminated sky beyond the range of the obscurity reflected an orange golden light. De La Rue, observing the same eclipse, says that the upper part of the sky was of a deep indigo colour, shading through a sepia tint into red and orange as it approached the horizon. Ranyard, observing the eclipse of 1870 in Sicily, describes the colour of the sky as a deep violet, which reminded him of the colour of the spectrum near the line H.

It has also been found that whilst the sky changes colour during the progress of an eclipse, similar effects are produced upon terrestrial objects. This seems to have been noticed as far back as 840 A.D.[d] Kepler mentions that during the solar eclipse which happened in the autumn of 1590, the reapers in Styria noticed that everything had a yellow tinge[e]. Similar effects have also been described in modern times[f]. De La Rue, in describing the eclipse of 1860, says that the peculiar light cast on the spectators impressed him with a feeling of solemnity never to be effaced.

The darkness which prevails during a total eclipse of the Sun is not usually so considerable as might be expected. It is, however, subject to much variation. Ferrer, speaking of the eclipse

[d] *Ad Vitellionem Paralipomena*, p. 294.

[e] *Ibid.*, p. 303.

[f] *Mem.* R.A.S., vol. xv. pp. 12, 14, and 15, 1846; xxi. *passim*, 1853; *Annuaire*, 1846, p. 291, &c.

of 1806, says that at the time of total obscuration "without doubt the light was greater than that of the full Moon [g]." In general it has been found that the darkness is sufficiently great to prevent persons from reading, though exceptions to this rule have been known. The faint illumination which exists at the moment of the totality is due to light reflected from those regions of the atmosphere which are still exposed to the direct rays of the Sun. The corona (which will presently be described) also, no doubt, assists in the illumination, but the light received from the corona is small compared with that derived from the clouds outside the region of totality, for it has frequently been noticed that the corona casts no shadow. The degree of obscuration will also vary according as the observer is or is not deeply immersed in the lunar shadow—a fact first pointed out by Halley [h].

Observers inside houses, or so situated amongst buildings that the light from the horizon cannot reach them, usually have difficulty in distinguishing objects during totality. Mountains or clouds upon the horizon and other local causes also seem to affect the degree of darkness, so that during the same eclipse the experience of observers in different localities may differ considerably. Thus during the total eclipse of 1851, Piazzi Smyth could read small print, while Professor Adams had only just sufficient light to read the face of a box chronometer; and Sir G. B. Airy says: "A candle had been lighted in a lantern about a quarter of an hour before the totality. Mr. Hasselgren was unable to read the minutes of the chronometer face, without having the lantern held close to the chronometer. I had prepared for the occasion a circle described upon a card: I desired much to make a drawing of the prominences, at least of their positions on the limb of the moon, by marking them on this circle, but it was impossible for me to see it, and I was obliged to approach very closely to the lantern, in order to make the smallest memorandum on the card."

Mr. Lassell, who observed the same eclipse at Trollhättan, said

[g] *Trans. Amer. Phil. Soc.*, vol. vi. p. 266. 1809.
[h] *Phil. Trans.*, vol. xxix. p. 250. 1715.

that the amount of darkness may be appreciated from the fact that on withdrawing his eye from the telescope he could neither see the seconds-hand of his watch nor the paper sufficiently to write the time down [i].

As previously remarked, a solar eclipse of large magnitude and still more a Total eclipse is always accompanied by a decided decrease in the temperature of the air (in the shade). Mr. G. J. Symons from observations in 1858, 1860, and 1870, concludes that the air is coldest about ½ hour after the time of the Conjunction of the Sun and Moon.

In the case of the eclipse of 1842, it was remarked by Piola at Lodi, and by O. Struve at Lipesk, that although the obscurity was such that stars of the 2nd and 3rd magnitudes ought to have been visible, yet only those of the 1st magnitude were actually seen [k]. M. Belli explained this curious fact by reference to a physiological principle. He remarked that during the short interval of total obscuration the eye has not sufficient time to recover from the dazzling effect of the Sun's rays, and consequently is unable to take advantage of the obscurity which actually prevails [l]. The suddenness with which the light succeeds the darkness after a total eclipse of the Sun is well known. Halley suggested 2 explanations of the phenomenon. 1st. That previously to the total obscuration the pupil of the eye might be very much contracted by viewing the Sun, and consequently the organ of vision would be less likely to suffer by the effulgence of the light than at the instant of emersion, when the pupil has again expanded. 2nd. That, as the Eastern margin of the Moon, at which the Sun disappeared, had been exposed for a fortnight to the direct action of the solar rays, the heat generated during this period might cause vapours to ascend in the lunar atmosphere, which, by their interposition between the Sun and the Earth, would have the effect of tempering the effulgence of the solar rays passing through them. On the other hand, the Western

[i] *Mem.* R.A.S., vol. xxi. p. 47, 1853; and see *Mem.* R.A.S., vol. xli. p. 185.

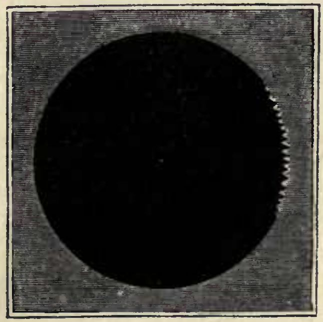
[k] *Giorn. dell' Ist. Lomb.*, vol. iv. p. 341; *Bibliothèque Universelle de Genève*, vol. xliv. p. 368.

[l] *Giorn. dell' Ist. Lomb.*, vol. iv. p. 341.

margin of the Moon, at which the Sun re-appeared, had just experienced a night of equal length, during which the vapours suspended in the lunar atmosphere had been undergoing a course of precipitation upon the Moon's surface under a process of cooling. In this case, therefore, the solar rays would meet with less obstruction in passing through the lunar atmosphere, and, consequently, it was reasonable to suppose that they would produce a more intense effect [m]. The second hypothesis requires us to suppose the presence of a lunar atmosphere, the existence of which modern observation tends to disprove. The first is doubtless the true explanation.

When the disc of the Moon advancing over that of the Sun has reduced the latter to a thin crescent, it is usually noticed that immediately before the beginning and after the end of complete obscuration, the crescent appears as a band of brilliant points, separated by dark spaces so as to give it the appearance of a string of beads which appear to move and merge into one another. While the Moon's limb is seen projected upon the sun's disc it appears perfectly smooth. No lunar mountains can be detected projecting beyond the general outline. The hypothesis usually advanced to account for this smoothness of the Moon's limb is that the irradiation from the bright background of the solar surface projects over the lunar limb like a fringe, and forms a new even limb inside the true rough lunar limb. As the solar crescent becomes thin, the irradiation fringe vanishes wherever a lunar projection breaks through the thin line of solar light.

Fig. 132.



"BAILY'S BEADS."

These phenomena are generally known as *Baily's Beads*, having received their name from the late Mr. Francis Baily, who was

[m] *Phil. Trans.*, vol. xxix. p. 248. 1715.

the first to describe them in detail[n]. His original memoir was published in 1836, and from it I make the following quotation:—

"When [previous to the totality] the cusps of the Sun were about 40° asunder, a row of lucid points, like a string of bright beads, irregular in size and distance from each other, *suddenly* formed round that part of the circumference of the Moon that was about to enter, or which might be considered as having just entered, on the Sun's disc. Its formation indeed was so rapid, that it presented the appearance of having been caused by the ignition of a train of gunpowder. This I intended to note as the correct time of the formation of the annulus, expecting every moment to see the thread of light completed round the Moon, and attributing this serrated appearance of the Moon's limb (as others had done before me) to the lunar mountains, although the remaining portion of the Moon's circumference was comparatively smooth and circular, as seen through the telescope. My surprise, however, was great on finding that these luminous points, as well as the dark intervening spaces, increased in magnitude, some of the contiguous ones appearing to run into each other like drops of water; for the rapidity of the change was so great, and the singularity of the appearance so fascinating and attractive, that the mind was for the moment distracted and lost in the contemplation of the scene, so as to be unable to attend to every minute occurrence. Finally, as the Moon pursued her course, these dark intervening spaces (which, at their origin, had the appearance of lunar mountains in high relief, and which still continued attached to the Sun's border) were stretched out into long, black, thick parallel lines, forming the limbs of the Sun and the Moon; when, all at once, they *suddenly* gave way, and left the circumferences of the Sun and Moon in those points, as in the rest, comparatively smooth and circular, and the Moon perceptibly advanced on the face of the Sun[o]."

Mr. Baily then goes on to describe the appearances which he saw after the total obscuration; they were, however, substantially the same as those recorded above.

The most recent full account of "Baily's Beads" is due to Mr. Lewis Swift, an American astronomer who observed the eclipse of July 29, 1878, at Denver, Colorado. He says:—

"At the eclipse of 1869, I was so captivated with the number, magnitude, and unexpected brilliancy of the protuberances, that I failed to give particular attention to the beautiful phenomenon of Baily's Beads. On this occasion I observed it very carefully, and found it one of the most striking and fascinating features of the whole eclipse. Several seconds previous to the formation of the beads, I observed, near each end of the solar crescent, a phenomenon which I have never seen described in the books. Though reminding me of the 'Black Drop,' which I saw at the late transit of Mercury, it was very different from it. At the risk of being considered prolix, I will describe it, though to be appreciated it must be seen. Imagine a long

[n] They were *noticed* long before his time.
[o] *Mem.* R.A.S., vol. x. p. 5. 1838.

and very narrow crescent cut in a door between two rooms, one brilliantly lighted, the other dark, the observer being in the farther end of the latter (imagined to be a very long one) looking at the crescent with his telescope. The appearance was as if two concealed persons in the lighted room, one each side of the crescent, were busily engaged in rapidly protruding and withdrawing a series of long slim black objects like slate pencils. They were not broad at their bases as is the 'Black Drop,' and, unlike the latter, were not, except in two instances, opposite each other. They were seen only near each end of the crescent. This phenomenon was as unique as it was unexpected, and lasted for but two or three seconds, and then entirely ceased at each end simultaneously, but recommenced in one or two seconds, but farther from the end of the lune, and the images were more blunt and less symmetrical, though their motions were as before. This lasted but a short time, when all motion ceased, as if preparing for a grand *denouement*, and from each end of the crescent, now reduced to a narrow curved line of light, the beads (which are luminous, and thus unlike the 'Black Drop') began to form from each end simultaneously, and in less than a half second were completed. They were nearly square, and increased in size from each end of the crescent to the centre, which was the largest in exact mathematical ratio. So symmetrical were they that if half of them had been superimposed on the other half they would have agreed in number, curvature, shape, and distance. They were visible but a short time—say two or three seconds—when, giving a few pulsating tremors, they vanished altogether. When I take into consideration the exact uniformity of their formation as to size, shape, etc., I cannot subscribe to the dogma that they are only the sun's light shining through the interstices of the lunar mountains. In this case part of the moon's contour, where they were formed, was smooth, while the other was exceedingly rough, yet the beads were the same in both localities. And those formed at the beginning are precisely similar to those at the close of totality, and those of one eclipse just like those of all—total and annular—that have occurred since they were first described by Baily. The assertion here seems justifiable that the cause of Baily's Beads is still enshrouded in darkness [p]."

The earliest account of the phenomenon of the beads is contained in Halley's memoir on the total eclipse of 1715. He says: "About 2 minutes before the total immersion, the remaining part of the Sun was reduced to a very fine horn, whose extremities seemed to lose their acuteness, and *to become round like stars*; and, for the space of about a quarter of a minute, a small piece of the Southern horn of the eclipse seemed to be *cut off from the rest* by a good interval, and appeared like an oblong star rounded at both ends [q]." The first annular eclipse in which it appears that any beads were seen was that of Feb. 18, 1736–7, observed by Maclaurin [r].

One of the most interesting appearances seen during a total

[p] *Washington Observations*, 1876, Appendix III. p. 227.

[q] *Phil. Trans.*, vol. xxix. p. 248. 1715.

[r] *Phil. Trans.*, vol. xl. p. 177. 1737.

eclipse of the Sun is the *corona*, or halo of light which surrounds the Moon. It usually appears only a few seconds previous to the total extinction of the Sun's light, and continues visible for about the same interval of time after its reappearance. In general, it may be compared to the nimbus commonly painted around the heads of the Virgin Mary, the Apostles, &c. Different explanations have been advanced to account for this phenomenon: Kepler thought it due to the presence of an atmosphere round the Moon [s]: La Hire suggested that it might be produced by the reflection of the solar rays from the inequalities of the Moon's surface, contiguous to the edge of her disc, combined with their subsequent passage through the Earth's atmosphere [t]; the late Professor Baden Powell once conducted a series of experiments which tended strongly to support the idea that refraction was the cause of it [u]: on the whole, however, it is now tolerably clear that it is due to something in the nature of *an atmosphere about the Sun.* Its figure, the nebulous structures which are seen in it all gradually diminishing in density onwards, point to the supposition of its being due to matter encompassing the solar orb, and gravitating everywhere towards its centre. Delisle conjectured that the luminous ring might be occasioned by the diffraction of the solar rays which pass near the Moon's edge [x], but Sir David Brewster shewed that this theory, though ingenious, is quite untenable [y].

Judged by photographic results, the solar corona is *very* much fainter than the Moon, for whilst its outer portion has been found to fail utterly to make any impression on a plate after an exposure of 5 seconds, the Moon has been photographed perfectly in 0·1 to 0·2 seconds. Moreover Federow in 1842; Swan and Chevallier in 1851; and Lespiault, Burat, and Cuillier in 1860, all observed, and specially recorded, that *no shadow* was cast by the corona.

The earliest historical allusion to the corona is made by Philostratus. He mentions that the death of the Emperor Domitian

[s] *Ad Vitell. Paralipom.*, p. 302; *Epit. Astron.*, p. 893.

[t] *Mém. Acad. des Sciences*, 1715, p. 161 *et seq.*

[u] *Mem.* R.A.S., vol. xvi. p. 301. 1847.

[x] *Mém. Acad. des Sciences*, 1715, p. 166 *et seq.*

[y] *Edin. Encyc.*, art. *Astronomy.*

had been 'announced' previously by a total eclipse of the sun. "In the heavens there appeared a prodigy of this nature. A certain *corona*, resembling the *Iris*, surrounded the orb of the Sun and obscured his light[z];" (*i.e.*, it appeared coincidently with the total obscuration of his light). Plutarch is still more precise in his allusion. Speaking of a total eclipse of the Sun which had recently happened, he endeavours to shew why the darkness arising from such phenomena is not so profound as that of night. He begins by assuming, as the basis of his reasoning, that the Earth greatly exceeds the Moon in size, and after citing some authorities, he goes on to say:—"Whence it happens that the Earth, on account of its magnitude, entirely conceals the Sun from our sight. . . . But even although the Moon should at any time *hide the whole of the Sun*, still the eclipse is deficient in duration, as well as amplitude, for a peculiar effulgence is seen around the circumference, which does not allow the obscurity to become very intense or complete." (Ἀλλὰ *περιφαίνεταί τις αὐγὴ περὶ τὴν ἴτυν, οὐκ ἐῶσα βαθεῖαν γίνεσθαι τὴν σκιὰν καὶ ἄκρατον*[a].) The luminous ring seems to have been noticed by Clavius during the eclipse of April 9, 1567: he thought that it was merely the uncovered margin of the Sun's disc; but Kepler shewed that this was impossible.

There are one or two well-authenticated instances of the corona being visible during partial eclipses of the Sun. In 1842, M. D'Hombre Firmas, at Alais, which was contiguous to, though not actually in the path of the shadow, states that, "every one remarked the circle of pale light which encompassed the Moon when she almost covered the Sun[b]." Several observers of this eclipse noticed that the ring at first appeared to be brightest on the side of the solar disc which was first covered by the Moon,

[z] *Life of Apollonius of Tyana*, by Philostratus, Bk. viii. cap. 23. The passage will be found quoted in *Ast. Nach.*, vol. xxvii. No. 1838, March 31, 1871; and in *Observatory*, vol. ix. p. 129, March 1886, where Lynn calls in question both the statements and the deductions which I have given in the text. But I am not satisfied that he has done so on sufficient grounds.

[a] Plut., *Opera Mor. et Phil.* vol. ix. p. 682. Ed. Lipsiæ, 1778.

[b] *Annuaire*, 1846, p. 339.

but that previously to the close of the total phase, it was brightest at the part where the Sun was about to reappear[c].

Not the least beautiful phenomena seen during a total solar eclipse are the "Red Flames," which become visible around the margin of the Moon's disc immediately after the commencement of the total phase. Mr. Dawes so minutely described them, as they appeared to him in July 1851, that I cannot do better than quote his words. He says:—

"Throughout the whole of the quadrant from north to east there was no visible protuberance, the corona being uniform and uninterrupted. Between the east and south points, and at an angle of about 115° from the north point, appeared a large red prominence of a very regular conical form. When first seen it might be about 1½′ in altitude from the edge of the Moon, but its length diminished as the Moon advanced.

"The position of this protuberance may be inaccurate to a few degrees, being more hastily noticed than the others. It was of a deep rose colour, and rather paler near the middle than at the edges.

"Proceeding southward, at about 145° from the north point, commenced a low ridge of red prominences, resembling in outline the tops of a very irregular range of hills. The highest of these probably did not exceed 40″. This ridge extended through 50° or 55°, and reached, therefore, to about 197° from the north point, its base being throughout formed by the sharply-defined edge of the Moon. The irregularities at the top of the ridge seemed to be permanent, but they certainly appeared to undulate from the west towards the east; probably an atmospheric phenomenon, as the wind was in the west.

"At about 220° commenced another low ridge of the same character, and extended to about 250°, less elevated than the other, and also less irregular in outline, except that at about 225° a very remarkable protuberance rose from it to an altitude of 1½′, or more. The tint of the low ridge was a rather pale pink; the colour of the more elevated prominence was decidedly deeper, and its brightness much more vivid. In form it resembled a *dog's tusk*, the convex side being northwards, and the concave to the south. The apex was somewhat acute. This protuberance, and the low ridge connected with it, were observed and estimated in height towards the end of the totality.

"A small double-pointed prominence was noticed at about 255°, and another low one with a broad base at about 263°. These were also of the rose-coloured tint, but rather paler than the large one at 225°.

"Almost directly preceding, or at 270°, appeared a bluntly triangular pink body, *suspended*, as it were, in the corona. This was separated from the Moon's edge when first seen, and the separation increased as the Moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening soft and ill-defined substance, like the upper part of a conical mountain, the lower portion of which was obscured by clouds or thick mist. I think the apex of this object must have been at least 1′ in altitude from the Moon's limb when first seen, and more than

[c] *Mem.* R.A.S., vol. xv. p. 16. 1846.

$1\frac{1}{2}'$ towards the end of total obscuration. Its colour was pink, and I thought it paler in the middle.

"To the north of this, at about 280° or 285°, appeared the most wonderful phenomenon of the whole, A red protuberance, of vivid brightness and very deep tint, arose to a height of, perhaps, $1\frac{1}{2}'$ when first seen, and increased in length to 2′, or more, as the Moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish cimeter*, the northern edge being convex, and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. Its northern edge was well defined, and of a deeper colour than the rest, especially towards its base. I should call it a *rich carmine.* The southern edge was less distinctly defined, and decidedly paler. It gave me the impression of a somewhat conical protuberance, partly hidden on its southern side by some intervening substance of a soft or flocculent character. The apex of this protuberance was paler than the base, and of a purplish tinge, and it certainly had a flickering motion. Its base was, from first to last, sharply bounded by the edge of the Moon. To my great astonishment, this marvellous object *continued visible for about* 5 *seconds,* as nearly as I could judge, *after the Sun began to reappear*, which took place many degrees to the south of the situation it occupied on the Moon's circumference. It then rapidly faded away, *but it did not vanish instantaneously.* From its extraordinary size, curious form, deep colour, and vivid brightness, this protuberance absorbed much of my attention; and I am, therefore, unable to state precisely what changes occurred in the other phenomena towards the end of the total obscuration.

"The arc from about 283° to the north point was entirely free from prominences, and also from any roseate tint."

Astronomers were long unable to determine the nature of these rose-coloured emanations; but it is now accepted that they belong to the Sun and consist of gaseous matter (chiefly hydrogen) in an incandescent state rushing upwards with inconceivable velocity.

One of these prominences, measured by De La Rue in 1860, was 44,000 miles in vertical height above the Sun's surface.

Julius Firmicus, speaking of the eclipse of July 17, 334, makes a remark which may apply to this phenomenon; otherwise the earliest recorded account of the Red Flames is by Captain Stannyan, who observed them at Berne during the total eclipse of 1706. He writes to Flamsteed:—

"That the Sun was totally darkened there for $4\frac{1}{2}$ minutes of time; that a fixed star and a planet appeared very bright; and *that his getting out of his eclipse was preceded by a blood-red streak of light from its left limb, which continued not longer than* 6 *or* 7 *seconds of time*; then part of the Sun's disc appeared all of a sudden, as bright as Venus was ever seen in the night; nay, brighter; and in that very instant gave a light and shadow to things as strong as the Moon uses to do[d]."

[d] *Phil. Trans.*, vol. xxv. p. 2240. 1706.

On this communication Flamsteed remarks ;—

"The Captain is the first man I ever heard of that took notice of a red streak preceding the emersion of the Sun's body from a total eclipse. And I take notice of it to you [the Royal Society], because it infers that the Moon has an atmosphere; and its short continuance, if only 6 or 7 seconds' time, tells us that its height was not more than 5 or 6 hundredths part of her diameter[e]."

The Red Flames were seen by Halley, Louville[f], and C. Hayes in 1715, and afterwards by Vassenius, at Göttenberg, who says :—

"But what seemed in the highest degree worthy, not merely of observation, but also of the attention of the illustrious Royal Society, were some reddish spots which appeared in the lunar atmosphere *without* the periphery of the Moon's disc, amounting to 3 or 4 in number, one of which was larger than the other, and occupied a situation about midway between the south and west. These spots seemed in each instance to be composed of 3 smaller parts or cloudy patches of unequal length, having a certain degree of obliquity to the periphery of the Moon. Having directed the attention of my companion to the phenomenon, who had the eyes of a lynx, I drew a sketch of its aspect; but while he, not being accustomed to the use of the telescope, was unable to find the Moon, I, again with great delight, perceived the same spot, or, if you choose, rather the invariable cloud occupying its former situation in the atmosphere near the Moon's periphery[g]."

A "Red-Flame" of a *greenish-blue* tinge has been noticed. This Arago considered to be an effect of contrast.

The Red Flames have also been noticed in annular eclipses, as in that of 1737, observed by Maclaurin, which appears to be the earliest in which the phenomenon was seen[h]; and in partial eclipses, of which that of 1605, observed by Kepler, is probably the first[i].

The aspect presented by the Moon during eclipses of the Sun is frequently very singular. Kepler stated that the Moon's surface is occasionally distinguishable by a ruddy hue[k]. Baily, in his account of the annular eclipse of 1836, states, that "previous to the formation of the ring, the face of the Moon was perfectly black; but on looking at it through the telescope, *during the annulus*, the circumference was tinged with a *reddish purple colour*, which extended over the whole disc, but increased in density of

[e] *Phil. Trans.*, vol. xx. p. 2241. 1706.
[f] *Mem.* R.A.S., vol. xxi. p. 90. 1853.
[g] *Phil. Trans.*, vol. xxviii. p. 135. 1733.
[h] *Phil. Trans.*, vol. xl. p. 181. 1737.
[i] *De Stellâ Novâ*, p. 116.
[k] *Epit. Astron.*, p. 895.

colour, according to the proximity to the centre, so as to be in that part nearly black[l]." Vassenius in 1733 and Ferrer in 1806 are the only observers who state that they have seen the irregularities in the Moon's surface during a central eclipse, whether total or annular[m]. Arago and others tried to do so in 1842, but failed. The fact that the lunar inequalities sometimes are seen and at other times are not seen is doubtless owing to meteorological causes.

In 1842 Arago saw the dark contour of the Moon projected upon the bright sky 40^m after the commencement of the eclipse. He ascribes the phenomenon to the projection of the Moon upon the solar atmosphere, the brightness of which, by an effect of contrast, rendered the outline of the Moon's dark limb discernible[n]. The phenomenon appears to be a rare one: at least it is recorded by only 3 recent observers[o].

On several occasions attempts have been made to detect the Moon's shadow in the course of its passage over the surface of the Earth. Airy in 1851 succeeded in observing it, but he failed in 1842, in which year, however, Plana and Forbes were more fortunate. The difficulty arises from the immense velocity of the shadow—about $30\frac{1}{2}$ miles per minute. The earliest historical record of the eclipse-shadow being seen occurs in Duillier's account of the eclipse of May 12, 1706[p].

According to M. Laussedat, one of the horns of the solar crescent in 1860 appeared for a short time rounded and truncated. The other horn was contracted nearly to a point, and a small patch of light wholly detached was visible beyond the extremity of this cusp.

[l] *Mem.* R.A.S., vol. x. p. 17. 1838.

[m] *Phil. Trans.*, vol. xxxviii. p. 135, 1733; *Trans. Amer. Phil. Soc.*, vol. vi. p. 267, 1809.

[n] *Annuaire*, 1846, p. 372.

[o] Noble, Pratt, and Neison, *Month. Not.*, vols. xxvii. p. 185, March 1867, and xxxiii. pp. 468 and 577, June, &c. 1873; *Ast. Reg.*, vol. xiii. p. 9, Jan. 1875.

[p] *Mém. Acad. des Sciences*, 1706, p. 113 (Hist.); *Phil. Trans.*, vol. xxv. p. 2243, 1706.

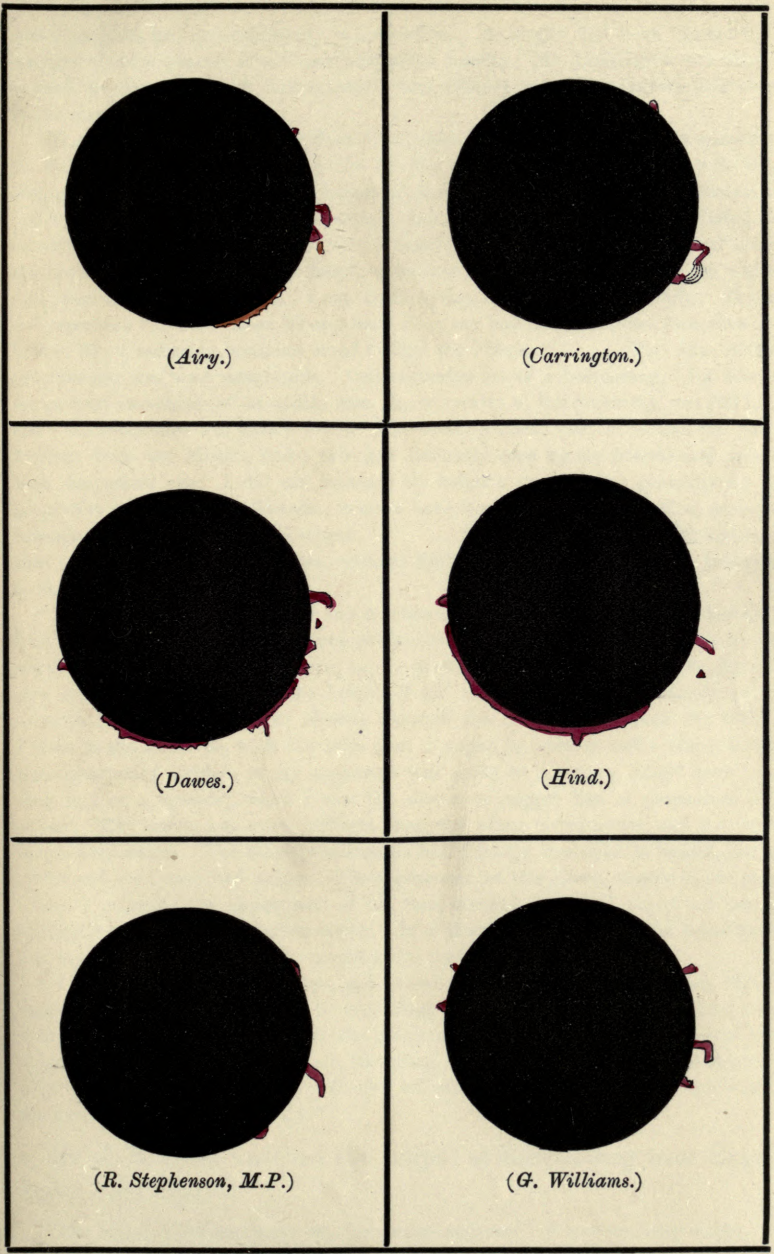
CHAPTER III.

THE TOTAL ECLIPSE OF THE SUN OF JULY 28, 1851.

Observations by Airy.—By Hind.—By Lassell.

NOT the least interesting of the total eclipses of the Sun that have occurred within the last half-century was that of July 28, 1851. Though not visible in England, it was seen to great advantage in Sweden, to which country many astronomers went at the time for the purpose of observing the eclipse. The following remarks are from the pen of Sir G. B. Airy, the then Astronomer Royal, who observed the eclipse at Göttenberg:—

"The approach of the totality was accompanied with that indescribably mysterious and gloomy appearance of the whole surrounding prospect, which I have seen on a former occasion. A patch of clear blue sky in the zenith became purple-black while I was gazing on it. I took off the higher power with which I had scrutinized the Sun, and put on the lowest power (magnifying about 34 times). With this I saw the mountains on the Moon perfectly well. I watched carefully the approach of the Moon's limb to that of the Sun, which my graduated dark glass enabled me to see in great perfection: I saw both limbs perfectly well defined to the last, and saw the line becoming narrower, and the curves becoming sharper, without any distortion or prolongation of the limbs. I saw the Moon's serrated limb advance up to the Sun's, and the light of the Sun glimmering through the hollows between the mountain peaks, and saw these glimmering spots extinguished one after another in extremely rapid succession, but without any of the appearances which Mr. Baily has described. . . . . I have no means of ascertaining whether the darkness really was greater in the eclipse of 1842. I am inclined to think, that in the wonderful, and, I may say, appalling obscurity, I saw the grey granite hills, within sight of Hvaläs, more distinctly than the darker country surrounding the Superga. But whether, because in 1851 the sky was much less clouded than in 1842 (so that the transition was from a more luminous state of sky, to a darkness nearly equal in both cases), or from whatever cause, the suddenness of the darkness in 1851 appeared to be much more striking than in 1842. My friends, who were on the upper rock, to which the path



THE TOTAL ECLIPSE OF THE SUN OF JULY 28, 1851.

VIEWS OF THE RED FLAMES.

was very good, had great difficulty in descending. A candle had been lighted in a lantern, about a quarter of an hour before the totality; Mr. Hasselgren was unable to read the minutes of the chronometer's face without having the lantern held close to the chronometer.

"The corona was far broader than that which I saw in 1842; roughly speaking, its breadth was a little less than the Moon's diameter, but its outline was very irregular. I did not remark any beams projecting from it which deserved notice as much more conspicuous than the others; but the whole was beamy, radiated in structure, and terminated (though very indefinitely) in a way which reminded me of the ornament frequently placed round a mariner's compass. Its colour was white, and resembling that of Venus. I saw no flickering or unsteadiness of light. It was not separated from the Moon by any dark ring, nor had it any annular structure: it looked like a radiating luminous cloud behind the Moon. . . . The form of the prominences was most remarkable. One reminded me of a boomerang. Its colour, for at least two-thirds of its width, from the convexity to the concavity, was full lake red; the remainder was nearly white. The most brilliant part of it was the swell farthest from the Moon's limb; this was distinctly seen by my friends and myself with the naked eye. I did not measure its height; but judging generally by its proportion to the Moon's diameter, it must have been 3′. This estimation, perhaps, belongs to a later period of the eclipse. . . . It was impossible to see the changes that took place in the prominences, without feeling the conviction that they belonged to the Sun, and not to the Moon.

"I again looked round, when I saw a scene of unexpected beauty. The southern part of the sky, as I have said, was covered with uniform white cloud; but in the northern part were detached clouds, upon a ground of clear sky. This clear sky was now strongly illuminated to the height of 30° or 35°, and through almost 90° of azimuth, with rosy red light shining through the intervals between the clouds. I went to the telescope, with the hope that I might be able to make the polarization-observation (which, as my apparatus was ready to my grasp, might have been done in 3 or 4 seconds), when I saw the *sierra*, or rugged line of projections, had arisen. This *sierra* was more brilliant than the other prominences, and its colour was nearly scarlet. The other prominences had perhaps increased in height, but no additional new ones had arisen. The appearance of this *sierra*, nearly in the place where I expected the appearance of the Sun, warned me that I ought not now to attempt any other physical observation. In a short time the white Sun burst forth, and the corona, and every other prominence, vanished.

"I withdrew from the telescope, and looked round. The country seemed, though rapidly, yet half unwillingly, to be recovering its usual cheerfulness. My eye, however, was caught by a duskiness in the south-east, and I immediately perceived that it was the eclipse-shadow in the air, travelling away in the direction of the shadow's path. For at least 6 seconds this shadow remained in sight, far more conspicuous to the eye than I had anticipated[a]."

Mr. J. R. Hind watched the eclipse at Rævelsberg, near Engelholm. He says:—

"The moment the Sun went out the corona appeared; it was not very bright, but this might arise from the interference of an extremely light cloud of the *cirrus* class

[a] *Mem.* R.A.S., vol. xxi. p. 5. 1853.

which overspread the Sun at the time. The corona was of the colour of tarnished silver, and its light seemed to fluctuate considerably, though without any appearance of revolving. Rays of light, the *aigrettes*, diverged from the Moon's limb in every direction, and appeared to be shining through the light of the corona. In the telescope many rose-coloured flames were noticed; one, far more remarkable than the rest, on the western limb, could be distinguished without any telescopic aid; it was curved near its extremity, and continued in view 4 *seconds after the Sun had disappeared*, *i.e.*, after the extinction of 'Baily's beads,' which phenomena were very conspicuous in this eclipse, particularly before the commencement of the totality. In this case they were clearly to be attributed to the existence of many mountains and valleys along the Moon's edge, the Sun's light shining through the valleys and between the mountain ridges, so as to produce the appearance of luminous drops or beads, which continued visible some seconds. The colour of the 'flames' was a full rose red at the borders, gradually fading off, towards the centres, to a very pale pink. Along the southern limb of the Moon, for 40° or upwards, there was a constant succession of very minute rose-coloured prominences, which appeared to be in a state of undulation, though without undergoing any material change of form. An extremely fine line, of a violet colour, separated these prominences from the dark limb of the Moon. The surface of our satellite, during the total eclipse, was purplish in the telescope; to the naked eye it was by no means very dark, but seemed to be faintly illuminated by a purplish grey light of uniform intensity, on every part of the surface.

"The aspect of nature during the total eclipse was grand beyond description. A diminution of light over the Earth was perceptible a quarter of an hour after the beginning of the eclipse; and about ten minutes before the extinction of the Sun, the gloom increased very perceptibly. The distant hills looked dull and misty, and the sea assumed a dusky appearance, like that it presents during rain; the daylight that remained had a yellowish tinge, and the azure blue of the sky deepened to a purplish violet hue, particularly towards the north. But notwithstanding these gradual changes, the observer could hardly be prepared for the wonderful spectacle that presented itself, when he withdrew his eye from the telescope, after the totality had come on, to gaze around him for a few seconds. The southern heavens were then of a uniform purple-grey colour, the only indications of the Sun's position being the luminous corona, the light of which contrasted strikingly with that of the surrounding sky. In the zenith and north of it, the heavens were of a purplish-violet, and appeared very near; while in the north-west and north-east, broad bands of yellowish crimson light, intensely bright, produced an effect which no person who witnessed it can ever forget. The crimson appeared to run over large portions of the sky in these directions, irrespective of the clouds. At higher altitudes the predominant colour was purple. All nature seemed to be overshadowed by an unnatural gloom. The distant hills were hardly visible, the sea turned lurid red, and persons standing near the observer had a pale livid look, calculated to produce the most painful sensations. The darkness, if it can be so termed, had no resemblance to that of night. At various places within the shadow, the planets Venus, Mercury, and Mars, and the brighter stars of the first magnitude, were plainly seen during the total eclipse. Venus was distinctly seen at Copenhagen, though the eclipse was only partial in that city; and at Dantzic she continued in view 10 minutes after the Sun had reappeared. Animals were frequently much affected. At Engelholm, a calf which commenced lowing violently as the gloom deepened, and lay down before the totality had commenced, went on feeding quietly enough very soon after the return of daylight. Cocks crowed at Elsinborg, though the Sun was only hidden there 30 seconds, and the birds sought their resting-places, as if night had come on [b]."

Mr. W. Lassell, who stationed himself near the Trollhätten Falls, thus describes the total obscuration:—

"I may attempt, but I cannot accomplish, an adequate description of the marvellous appearances, and their effect upon the mind, which were crowded into this small space of 3⅓ minutes,—an interval which seemed to fly as if it were composed of seconds and not of minutes! Perhaps a naked-eye observer would more fully grasp the awful effect of the sudden extinguishment of light,—the most overpowering of these appearances,—for, my eye being directed through the telescope, I must have been less, though sufficiently, struck with the unprecedented sensation of such instantaneous gloom. The amount of darkness may be appreciated from the fact that, on withdrawing my eye from the telescope, I could neither see the second-hands of my watch, nor the paper sufficiently to write the time down; and was only able to do so by going to the candle, which I had by me burning on the table. Probably the suddenness of the gloom, not giving time for the expansion of the pupil of the eye, increased the sensation of apparent darkness; as I was obliged to repair close to the candle for the requisite light. After registering the time, I looked out for a few minutes with the naked eye over the landscape, north and south. The north was clear, and the line of horizon could be distinctly seen. The Sun, covered by the Moon, looking like a blue patch in the sky, had now the corona very symmetrically formed around it; but the Moon appeared to my unassisted eye to be not very round or smooth at its edge,—more as if one had rudely cut out with a knife on a board a circular disc of card,—the edges somewhat jagged and irregular in outline.

"The corona itself was perfectly concentric and radiating, some of the rays appearing in some parts of the circumference a *little* longer than in others; but the inequality was not great. I am unable to say whether the corona when *first* found was at all eccentric, for, as it is evident that any one observing with a telescope up to the moment of obscuration must have time to take off the dark glass before the corona can be seen, and as I had also to note the *time*, the centres of the Sun and Moon must have been pretty closely approximating before I again applied the eye to the telescope. It was indeed a great exercise of self-denial to spare the time from the exciting phenomena, which was necessary for accurately recording the duration of total darkness; but being inclined to think such record would be disregarded by many observers, I took my resolution to secure it."

The writer then proceeds to say that Venus was the only object visible to the naked eye. The corona he describes as "brilliant," and he considers that it afforded, speaking roughly, as much light as the Moon usually does when at its full.

"I had intended to direct my attention pointedly to the detection of the 'Red Flames,' which I had heard described as but faint phenomena. My surprise and astonishment may therefore be well imagined when the view presented itself

[b] *Sol. Syst.*, p. 71.

instantly to my eye as I am about to describe, or rather to attempt to give a notion of.

"In the middle of the field was the body of the Moon, rendered visible enough by the light of the corona around, attended by the apparent projections from behind the Moon of which I have attempted to sketch the positions. The effect upon my own mind of the awful grandeur of the spectacle I feel I cannot fully communicate. The prominences were of the most brilliant lake colour,—a splendid pink, quite defined and hard. They appeared to me to be not quiescent; but the Moon passing over them, and therefore exhibiting them in different phase, might convey an idea of motion. They are evidently to my senses belonging to the Sun and not at all to the Moon; for, especially on the western side of the Sun, I observed that the Moon passed over them, revealing successive portions of them as it advanced. In conformity with this observation also, I observed only the summit of *one*, on the eastern side, though my friends observing in adjoining rooms had seen at least two: the time occupied by my noticing the time and observing with the naked eye not having allowed me to repair again to the telescope until the Moon had covered one, and three-fourths of the other. The point of the Sun's limit where the principal 'flame' appeared was (I judged) a few degrees south of the place where the cluster of spots was situated, and the flame which I observed on the eastern limb was almost exactly where the eastern spot was situated. As, however, some prominences appeared adjacent to parts of the Sun's limit not usually traversed by spots, the attempt to trace a connexion fails. The first burst of light from the emergent Sun was exactly in the place of the chief western flame, which it instantly extinguished. . . . . . . From the varying lengths of the red flames it is difficult to give an accurate estimation of their magnitude; but the extreme length of the largest, on the western limb, may have been about $2\frac{1}{2}'$. This estimation is rather rude, as I was so absorbed in contemplating their general phenomena that I had not time for exact measurement [c]."

[c] *Mem.* R.A.S., vol. xxi. p. 47. 1853.

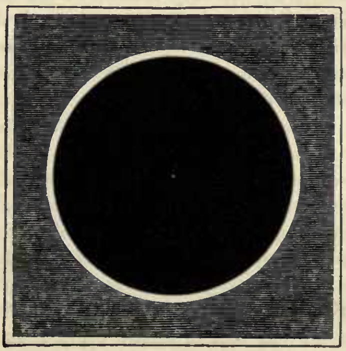
CHAPTER IV.

THE ANNULAR ECLIPSE OF THE SUN OF MARCH 14–15, 1858.

Summary of observations in England.

OF the different eclipses which have from time to time been visible in England, few have attracted such interest and attention among all classes of society as that of March 14–15, 1858. Though bad weather in most cases interrupted or altogether prevented observations, yet many instructive features were noticed.

Fig. 139.



ECLIPSE OF THE SUN, March 14–15, 1858; THE ANNULUS.

The line of central and annular eclipse passed across England from Lyme Regis, in Dorsetshire, to the Wash, between Lincolnshire and Norfolk, traversing portions of Somersetshire, Wiltshire, Berkshire, Oxfordshire, and Northamptonshire. The following summary of the observations made, drawn up by Mr. Glaisher, will be read with interest:—

"From returns received between Braemar and the Channel Islands, from 30 to 40 in number, it is shewn that the depression of temperature during the eclipse was about $2\frac{1}{2}°$ at stations north of the line, and nearly $3°$ at stations on and south of the line of central eclipse; that at places where the usual diurnal increase had taken place in the morning the depression of temperature during the eclipse was greater: and that at places where such increase had not taken place it was less than the above numbers. Also that at places where the sky was uniformly cloudy during the day the decrease in the readings of a black bulb thermometer was less than 12°, while at places where the sky was partially clear the depression was from 17° to 19°, and that, what temperature soever the black bulb thermometer indicated in the morning, it fell during the eclipse to that of the temperature of the air at all places.

"The humidity of the air was such that at places north of the line the wet bulb thermometer read 2·6° less; and on and near the line the depression was 3·2°, and south of it was 3·7° below the adjacent dry bulb thermometer.

"At some places the humidity of the air increased at the time of the greatest eclipse, but this was far from being universal.

"The sky was partially clear at some places on the east and south coasts, in the Channel Islands and north of Scotland, and it was for the most part overcast elsewhere. Near the southern extremity of the central line the sky was partially clear, and at its northern extremity near Peterborough the clouds were broken; at most intermediate places the sky was wholly overcast. The complete ring was seen at Charmouth, and neighbourhood near Lyme Regis, and at Peterborough, but, so far as I can learn, at no other places. My own station was on the calculated line of central eclipse, near Oundle, in Northamptonshire, and here I saw the Moon and Sun's apparent upper limb coincident, or very nearly so, and therefore that I was situated on or very near the northern limit of annularity, but distant from the centre line by 3 or 4 miles.

"It is very much to be regretted that the unfavourable weather precluded the witnessing the very beautiful attendant phenomena upon large solar eclipses. The time of year was unfavourable to all optical effects—whether of light and shade or colour, independently of the particular character of the day, which was more fatal still to their exhibition, for even where the Sun was visible their presence was only feebly indicated at a few parts of the country.

"At Oundle the weather for some time previous to the commencement of the eclipse was raw and ungenial for the time of year. The wind was gusty and the sky overcast, chiefly with cirro-stratus, and dark scud hurrying past the Sun's place from the north-west, the clouds occasionally giving way and allowing the Sun to be visible by glimpses. Shortly after 1 o'clock the sky became uniformly overcast, and a small steady rain set in for a considerable time.

"It was long before any sensible diminution of light took place. At $12^h\ 39^m$ a gloom was for the first time perceptible to the north, and the crescent of the Sun shone out with a bright white light between breaks. At $0^h\ 43^m$ the gloom was general, excepting around the Sun, which appeared the centre of a circle of light, and illuminated with fine effect some bold irregular masses of cumulus in its vicinity. At $0^h\ 45^m$ the gloom increased, slight rain fell, and the wind rose, birds were heard chirping and calling. At $0^h\ 53^m$ a severe storm might have been supposed impending, and numerous birds were flying homewards. The deepening of the gloom was gradual but very slow, and between 1^h and $1^h\ 1^m$ was at its greatest intensity; but even at this time the obscurity was not sufficient to require that any employment should be suspended. Messrs. Adams and Symons, situated five feet from a shed in an adjoining brickfield, spoke of the gloom as very intense for a period of 10 seconds, and sufficient to render it difficult to take the readings of the thermometer. A body of rooks rose from the ground at this moment and flew homewards; a flock of starlings rose together, and various small birds flew wildly about; a hare was seen to run across a neighbouring field, as though it were daybreak; straw rustled, and the silence was peculiar and intense. The darkness and lull was that of an approaching thunder-storm. Directly after the greatest intensity the gloom was sensibly and instantaneously diminished, and the day was speedily restored to its ordinary appearance.

"After 0^h 50^m the lark ceased to rise, and did not sing; at 1^h 10^m it rose again. The collected information tends to shew that birds and animals, but particularly the former, were affected in some degree in most places; and that it is probable to suppose the gloom was referred by them to the approach of evening, and this not so much from the fact of the gloom as from the manner of its approach, without the accompanying signs of atmospheric disturbance which usher in a storm, and to which birds and animals are keenly sensitive.

"All over the country rooks seem to have returned to their rookeries during the greatest obscuration; starlings were seen in many places taking flight, whole flocks of them together. At Oxford Dr. Collingwood remarked that a thrush commenced its evening song. At Grantham pigeons returned to their cote. At Ventnor Dr. Martin notes the fact that a fish confined in an aquarium, and ordinarily visible at evening only, was in full activity about the time of the greatest gloom. In Greenwich Park the birds were hushed and flew low from bush to bush, and at nearly all places the song of many birds was suspended during the darkness. At Campden Hill it was observed that the crocus closed about the same time, and at Teignmouth that its colour changed to that of the pink hepatica.

"The darkness was not sufficient at any place to prevent moderate-sized print being read at any convenient distance from the eye out of doors, but a difficulty was sometimes experienced in reading the instruments. At Grantham the darkness is described to have been about equal to the usual amount of light an hour before sunrise; near Oxford as about equal to that just after sunset on a cloudy day. The general impression communicated was that of an approaching thunder-storm. The sudden clearing up of the gloom after the greatest phase was likened by more than one observer to the gradual, but somewhat rapid withdrawal of a curtain from the window of a darkened room. The darkness is described to have been generally attended by a sensation of chilliness and moisture in the air. At Oxford the clouds surrounding the Sun were beautifully tinted with red, which merged into purple as the obscuration increased. At Grantham as the eclipse progressed the light became of a decided grey cast, similar to that of early morning, but at the time of the greatest gloom it had a strong yellow tinge. At Teignmouth the diminution of light was very great; the sombre tints of the clouds became much deepened, and the remaining light thrown over the landscape was lurid and unnatural. At Greenwich the appearance of the landscape changed from a dull white to a leaden, and then to a slate-coloured hue; and as the darkness increased it had much the appearance of a November fog closing in on all sides. At Wakefield the tints of the clouds changed from the grey slate colour of clouds in a storm, and became of a purple hue. At Oundle, my own station, the clouds were one uniform leaden grey or slate-colour, and quite in accordance with the general character of the day, nor could I perceive that the clouds appeared lower, or, in fact, that there was any very noticeable departure from the gloom we constantly experience during dull winter weather. Throughout the eclipse it occurred to me that the illuminating power of the Sun was much more than might have been supposed commensurate with the unobscured portion of the disc. When casual breaks permitted it to be visible the illuminated crescent up to the time of the greatest phase emitted beams of considerable brilliancy, which marked out a luminous track in the gloom, and were clearly and well defined in extent and figure. As the eclipse proceeded a decided change was to be observed in the colour of the Sun itself, which became of a pure silvery brightness, like that of Venus after inferior conjunction with the Sun. The absence of all colour in the light was remarkable, and at the time when the annulus was nearly formed it appeared like a line of silver wire. The departure from the usual amount of light we are accustomed to receive on an ordinarily dull day during the greater part of the eclipse was so inconsiderable, that we might infer approximately the real amount of Sun our average daylight under a cloudy sky is equivalent to.

"As a photometric test during the eclipse, strips of photographic paper were exposed for equal intervals of time every 5 minutes. The result was a scale of tints which exhibited clearly the diminishing intensity of the light up to the period of greatest obscuration, and the rapid increase beyond. The range of tints is low, owing to the cloudy state of the sky, but this does not interfere with the proportionate depths of tint; the time of greatest darkness is distinctly shewn by the very feeble discoloration of the paper. The instruments used at Oundle were made specially for those observations, and were of a very delicate and accurate construction; the meteorological observations were made by Messrs. Adams and Symons.

"In conclusion, I beg sincerely to thank those gentlemen whose returns have supplied the data for this investigation, of which we may say, literally as well as figuratively, that it exhibits only the faint outline of facts dimly visible through a screen of clouds. I think, however, it is reasonable to infer that the great paucity of effects and general phenomena witnessed even in places where the Sun was visible, is due to the conditions of the atmosphere, attributable alike to climate, time of year, and unfavourable weather, and should by no means lessen our confidence in previous accounts of the grandeur and beauty of the attendant phenomenon upon solar eclipses. Optical phenomena, we all know, are dependent upon the medium through which we view them for the nature and power of the effects produced."

Defective as this record is, from a scientific point of view, owing to the unfavourable weather having so generally interfered with observations, yet it has some interest to Englishmen by reason of the fact that phenomena of this character are so rarely visible in England.

CHAPTER V.

THE TOTAL ECLIPSE OF THE SUN OF JULY 18, 1860.

Extracts from the observations of Sir G. B. Airy.—Observations of the Red Flames by Bruhns.—Meteorological observations by Lowe.

THE total eclipse of July 18, 1860, presented some noticeable features: it owed its interest to the agreeable circumstances connected with it[a], and its importance to the very extensive observations which were made by many astronomers in Europe, Africa, and America.

Sir G. B. Airy stationed himself at the village of Pobes in the North of Spain. From his memoir[b] I make the following extracts:—

"On the progress of the eclipse I have nothing to remark, except that I thought the singular darkening of the landscape, whose character is peculiar to an eclipse, to be sadder than usual. The cause of this peculiar character I conceive to be the diminution of light in the higher strata of the air. When the Sun is heavily clouded, still the upper atmosphere is brilliantly illuminated, and the diffused light which comes from it is agreeable to the eye. But when the Sun is partially eclipsed, the illumination of the atmosphere for many miles round is also diminished, and the eye is oppressed by the absence of the light which usually comes from it.

"I had a wax candle lighted in a lantern, as I have had at preceding total eclipses. Correcting the appreciations of my eye by reference to this, I found that the darkness of the approaching totality was much less striking than in the eclipses of 1842 and 1851. In my anxiety to lose nothing at the telescope I did not see the approach of the dark shadow through the air; but, from what I afterwards saw of its retreat, I am sure it must have been very awful."

[a] It is to the *Himalaya* expedition to Spain that allusion is here made.
[b] *Month. Not.*, vol. xxi. p. 9. Nov. 1860.

After describing the Red Flames he says:—

"I may take this opportunity of stating, that the colour of these appearances was not identical with that which I saw in 1842 and 1851. The *quality* of the colour was precisely the same (full blush-red, or nearly lake), but it was diluted with white, and more diluted at the roots of the prominences close to the Moon's limb than in the most elevated points.

"About the middle of the totality I ceased for awhile my measures, in order to view the prospect with the naked eye. The general light appeared to me much greater than in the eclipses of 1842 and 1851 (one cloudy, the other hazy), perhaps 10 times as great; I believe I could have read a chronometer at the distance of 12 inches; nevertheless, it was not easy to walk where the ground was in the least uneven, and much attention to the footing was necessary. The outlines of the mountains were clear, but all distances were totally lost; they were in fact an undivided mass of black to within a small distance of the spectator. Above these, to the height perhaps of 6° or 8°, and especially remarkable on the north side, was a brilliant yellow or orange sky, without any trace of the lovely blush which I saw in 1851. Higher still, the sky was moderately dark, but not so dark as in former eclipses. The corona gave a considerable body, but I did not remark either by eye-view or by telescope-view anything annular in its structure; it appeared to me to resemble, with some irregularities (as I stated in 1851), the ornament round a compass card. But the thing which struck me most was the great brilliancy of Jupiter and Procyon so near the Sun. It was impossible that they could have been seen at all, except under the circumstance of total absence of illumination on that part of the atmosphere through which the light passed. I returned to my measures, but I was soon surprised by the appearance of the scarlet sierra, announcing the approach of the Sun's limb. It disappointed me, for I had reckoned on a much longer time. All our party who were aware of the predicted duration fully believed that it must have been very erroneous. How the time passed I cannot tell. The Sun at length appeared, extinguishing the sierra, but the prominence and cloud remained visible, and my last measures were taken after reappearance. The prominences, &c. were then rapidly fading, and I quitted the telescope, not without the feeling that I had not done all that I had intended or hoped to do."

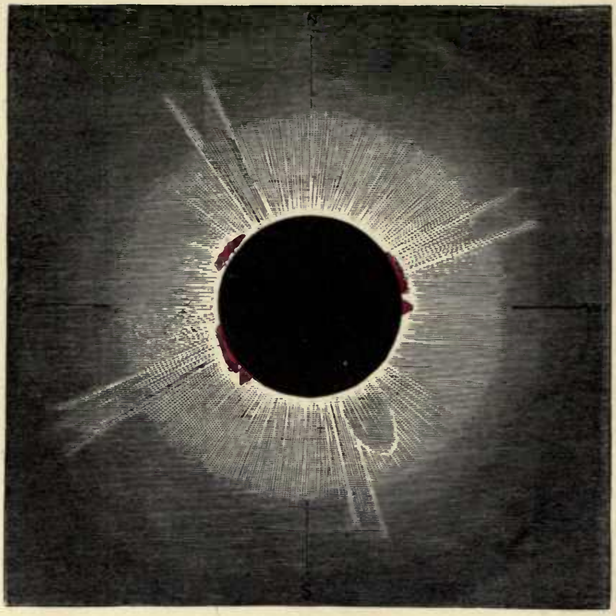
The Red Flames were seen, and described by many of the observers; the account given by M. Bruhns is the most complete[c]. He says:—

"Just before the totality, there was visible, on the western border of the Moon, only one protuberance and the corona; but as the last rays of the Sun disappeared, more protuberances started out on the eastern side, and the corona shone forth with an intense white light, so lustrous in fact as to dim the protuberances. I remarked that I saw them better when a clear red glass was held before my eye.

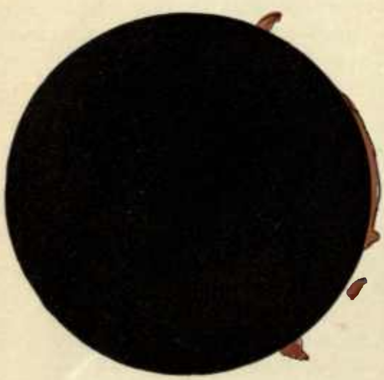
"During the totality I sketched 4 drawings, and also measured off the position-angles of the different protuberances, counting round the circle from the north point through the east, &c.

"The figure marked [Fig. 141, Pl. XIX] was drawn during the first minute of the totality. The first protuberance is the one already mentioned; its position-angle

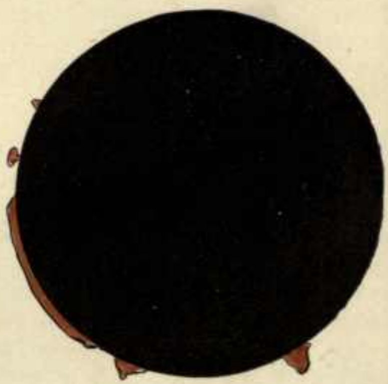
[c] *Ast. Nach.*, vol. liv. No. 1292. Jan. 22, 1861.



(*Feilitzsch.*)



(*Bruhns.*)



(*Bruhns.*)

THE TOTAL ECLIPSE OF THE SUN OF JULY 18, 1860.

TELESCOPIC VIEWS OF THE CORONA AND RED FLAMES.

was 35°, the length of its base 1½′ or 2′, and its height about the same. The summit was somewhat curved, of an intense rose colour, but a little paler at the apex.

"The second protuberance, situated at 60°, was completely separated from the Moon, there being between them an interval of ½′. For part of its extent it was parallel to the Moon's border, it then deviated from it, and ended in a point. Its length was 1½′ or 2′, its height about ½′, and of a rose-colour.

"The third protuberance, having a position-angle of 75°, resembled a mountain, and had a base of 1½′, and a height of fully ½′. Extending onwards for 50° from this protuberance was a narrow fringe, first of a pale red, but a few seconds afterwards it came over a splendid rose colour, and of a height of about ½′, which soon narrowed as the Moon passed over it, until at length it was quite covered.

"A fourth protuberance existed at 155°; its base was not more than ¾′, but the height was as much as 1½′. It had a hooked form with the curve trending northwards, and likewise of a rose colour.

"During no part of the totality were there any protuberances visible in the southern part of the Sun's disc.

"In the second minute the above-described protuberances became gradually smaller; with the exception of the first, which retained its magnitude and figure almost unchanged. The above-described unattached protuberance [No. 2] was reached by the Moon, and became gradually covered. By the end of the second minute the fringe was entirely covered, and at this juncture, on turning to examine the western border of the Moon, I perceived several protuberances, not previously visible.

"The protuberance situated at 260°, which I will call No. 5, had, at the beginning of the second [third?] minute, only a base of ½′, and about the same height, the colour being rose.

"Between 270° and 300° extended a second streak about ¼′ in height.

"A sixth protuberance was visible at 310°, having a base of 2′, and a height of ¾′.

"Lastly, I found at 340° a seventh protuberance, having a base of 1′, and a height of ¾′, and of a rose colour, like all the preceding.

"On directing my attention to the first protuberance (the one at 35°), I fancied it had grown considerably larger. The sharp edge, first seen, had disappeared, and for a height of 3′ or 4′ flaming rays could be discerned, the colour (at the base a bright rose) was, at the top, hardly perceptible, but seemed to fade off and become merged in the corona.

"After I had observed these for about half a minute, without perceiving any alteration, I quitted the telescope to observe the corona and the sky for a short time with the naked eye. The black-looking Moon was surrounded by a crown of clear light of unequal breadth. Below [S.] it was considerably greater than above [N.]. I estimated that in the former case it was ⅜°, in the latter about ¼°, and the general appearance of the thing gave me the idea that the Moon was eccentrically placed in the corona.

"The general form of the corona appeared circular, but on the eastern side a long ray shot out to a distance of about 1°; the breadth of its base was 3′, but it tapered down to about 1½′. During the 10 seconds that my attention was directed to it, neither the direction nor the length of the ray altered; its light was considerably feebler than that of the corona, which was of a glowing white, and seemed to coruscate or twinkle.

"With the naked eye I easily saw Venus and Jupiter, the former being much brighter than the latter. Although I knew whereabouts Procyon, Castor, Pollux, Mercury, and Saturn were, yet in the few seconds available for seeking for them I failed to find them.

"My assistant, M. Auerbach, who observed the corona, and searched for the stars during a longer period than I did, noticed in the south-western quadrant a curved ray about $\frac{1}{10}°$ in length, which I in my hurry probably overlooked. He also saw Pollux, and another person saw Castor; but, as far as I am aware, no more than the above 4 objects were seen by any person in Tarragona.

"Towards the end of the 3rd minute of the totality, I again looked through the telescope, and made the drawing [Fig. 142, Pl. XIX]. The western protuberances had altered considerably since the 2nd minute; the one at 35° had regained its original form and size, the flaming rays, previously spoken of, having disappeared. The protuberance in 340° had become much larger, the length of its base being now about 2′, and the height $1\frac{1}{2}'$. The red streak extending from 270° to 300° had prolonged itself so as to take in the protuberance at 310° [No. 6], and had altogether now a length of 50°, its height having also become augmented from $\frac{1}{4}'$ to 1′, and its colour being an intense rose. The protuberance at 260° [No. 5] was now separated by about $\frac{1}{4}'$ from the Moon, its breadth being nearly 1′, and its height $\frac{1}{2}'$. Finally, at 240° a new and small protuberance had started into view, its base and height were both about $\frac{1}{2}'$, and rose-coloured.

"As the end of the totality advanced so the protuberances became less distinct, the colour became brighter, and immediately after the 3rd minute of totality the protuberances at 240° and 260° disappeared; the fringe extending itself to a length of more than 90°, its height being $1\frac{1}{2}'$, and embraced all the protuberances up to an angle of 35°. On the first appearance of the solar rays all suddenly vanished, with the exception of the first protuberance, which for some time afterwards remained visible in the thin red glass."

Meteorology was not unrepresented in Spain, for Mr. E. J. Lowe, at Fuente del Mar, near Santander, with 2 assistants, during a period of 5 hours, made upwards of 4000 observations. The following is an abstract of Mr. Lowe's results, in his own words:—

"Commencing with underground temperature, a thermometer placed 6 inches below the surface of the ground ranged between 67·9° and 70·7°, *i.e.* 2·8°; at this depth the eclipse was not sensibly felt, whereas other thermometers, placed 4 inches, 2 inches, 1 inch, and $\frac{1}{2}$ an inch below the surface, all exhibited in a very marked manner the effect of the eclipse. On the grass the temperature fell to 64° at $3^h\ 5^m$; at $\frac{1}{2}$ inch below the surface, to 69° at $3^h\ 15^m$; at 1 inch deep, to 69·5° at $3^h\ 25^m$; at 2 inches, to 71° at $3^h\ 55^m$; at 4 inches, to 70·7° at $4^h\ 30^m$ P.M.

"The temperature on the grass was 77·5° at noon, rising to 91·7° at $1^h\ 50^m$, and then falling till $3^h\ 5^m$, and again rising to 85° at $4^h\ 10^m$, giving a range of 27·7°. At half an inch below the surface of the ground the temperature rose till $1^h\ 55^m$ P.M., when it was 78·5°, and then gradually fell to 69°, rising again to 74·7° at $4^h\ 30^m$ P.M., the range being 9·5°. At 1 inch below the surface the temperature rose till $1^h\ 55^m$ to 76·2°, fell till $3^h\ 25^m$ to 69·5°, and rose till $4^h\ 55^m$ to 74·7°, the range being 6·7°. At

Fig. 143. *Plate* XX.

THE TOTAL ECLIPSE OF THE SUN OF JULY 18, 1860. (*Tempel.*)

2 inches below the surface the temperature rose till 2^h 5^m to 74·4°, then fell till 3^h 55^m to 71·0°, and afterwards rose till 4^h 55^m to 73·7°, the range being 3·4°; and at 4 inches below the surface the temperature rose till 2^h 50^m to 73°, then fell till 4^h 30^m to 70·7°, and again rose till 6^h P.M. to 73·2°, the range being 2·5°.

"The greatest cold on the ground occurred between 3^h and 3^h 5^m P.M.; ditto, ½ an inch below surface, 3^h 10^m and 3^h 15^m P.M.; ditto, 1 inch, 3^h 20^m and 3^h 25^m P.M.; ditto, 2 inches, 3^h 50^m and 3^h 55^m P.M.; ditto, 4 inches, 4^h 25^m and 4^h 30^m P.M.

TABLE OF TEMPERATURES.

	Commencement of Eclipse.	Middle of Eclipse.	End of Eclipse.	Range during Eclipse.
	°	°	°	°
Of a blackened ball on grass	104·0	65·5	94·0	38·5
Of a blackened ball in vacuo	131·0	66·0	104·0	65·0
In sunshine at 2 feet above ground ...	75·5	63·6	70·0	11·9
In sunshine 2 feet (wet bulb)	69·5	59·3	65·5	10·2
Diff. between dry and wet bulb at 2 feet	6·0	4·4	4·5	1·6
In shade at 4 feet	70·0	64·7	71·0	6·3
In shade at 4 feet (wet bulb)...	62·5	59·7	63·5	3·8
In shade at 3 feet	70·2	64·2	70·7	6·5
In shade at 2 feet	68·5	62·5	68·5	6·0
In shade at 1 foot	70·7	64·5	70·2	5·7

"The barometer rose from 1^h 40^m till 2^h 10^m 0·002 inch, then fell till 3^h 5^m 0·0017 inch, and rose till end of eclipse, 0·009 inch.

"Intensity of photographic light, from salted papers conveyed, sensitised, in Marion's dark box, exposed for 10 seconds (with a scale of from 0 to 5°), at the commencement of the eclipse, 4½° becoming 4° at 2^h 5^m, 3° at 2^h 15^m, 2° at 2^h 25^m, 1° at 2^h 40^m, ¾° at 2^h 50^m, 1° at 2^h 55^m (clear about Sun), ¼° at 3^h, 1° at 3^h 5^m, 2° at 3^h 25^m, 2½° at 3^h 40^m, 3° at 3^h 50^m, and 4° at 4^h. During totality a paper exposed for 1 minute gave ¾°.

"The wind was N.W. and N.N.W. till 4^h 20^m, then W.S.W., being S.W. at 4^h 25^m, and South at 4^h 45^m. The wind was brisk at the commencement of the eclipse, quite a calm during totality, and a gentle breeze afterwards. The distant prospect was very clear, except during totality, when the mountains disappeared, and only near objects were visible.

"The clouds, which were chiefly cumuli, diminished in amount till 1^h 50^m, when only $\frac{4}{10}$ of the sky was overcast, then increased till 2^h 35^m with much cloud till 3^h 55^m, then again diminished to $\frac{6}{10}$ at the termination of the eclipse, the range being $\frac{5.5}{10}$ of the whole sky. Towards totality some of the cumuli became scud, which lasted from 2^h 5^m to 3^h 10^m, giving the strongest impression that the change was due to the eclipse.

"The morning was fine, and from 12^h 45^m P.M. sunshine; at 1^h 25^m much open sky about the zenith; at 2^h 15^m a blackness about W. horizon, and slightly so in N. and S.; at 2^h 30^m the hills dark, and the blue sky in N. and E. very pale in colour; at 2^h 35^m, hills dark, with a blue haze among the more distant mountains; at 2^h 40^m, horizon due W. pink; at 2^h 45^m, clear sky, in N. pink; at 2^h 52^m, splendid pink in W. horizon, warm purple in summits of mountains in S., clear sky, in N. deep lilac, and in E. very pale blue; at 2^h 57^m, rapid change, the clear sky in N. deep marine blue with a red line.

"Before totality commenced, the colours in the sky and in the hills were magnificent beyond all description; the clear sky in N. assumed a deep indigo colour, while in the W. the horizon was pitch black (like night). In the E. the clear sky was very pale blue, with orange and red, like sunrise, and the hills in S. were very red; on the shadow sweeping across, the deep blue in N. changed like magic to pale sunrise tints of orange and red, while the sunrise appearance in E. had changed to indigo. The colours increased in brilliancy near the horizon, overhead the sky was [of a] leaden [hue]. Some white houses at a little distance were brought nearer, and assumed a warm yellow tint; the darkness was great; thermometers could not be read. The countenances of men were of a livid pink. The Spaniards lay down, and their children screamed with fear; fowls hastened to roost, ducks clustered together, pigeons dashed against the sides of the houses, flowers closed (*Hibiscus Africanus* as early as 2^h 5^m); at 2^h 52^m cocks began to crow (ceasing at 2^h 57^m, and recommencing at 3^h 5^m). As darkness came on, many butterflies, which were seen about, flew as if drunk, and at last disappeared; the air became very humid, so much so that the grass felt to one of the observers as if recently rained upon. So many facts have been noted and recorded that it is impossible to do more than give a brief statement of the leading features."

The general result of the observations of the eclipse of 1860 was to shew conclusively that the Red Flames in solar eclipses belong not to the Moon but to the Sun.

An interesting and valuable memoir on this eclipse was presented to the Royal Society by Mr. Warren De La Rue[d].

[d] *Phil. Trans.*, vol. clii., 1862.

CHAPTER VI.

RECENT TOTAL ECLIPSES OF THE SUN.

Eclipse of August 18, 1868.—*Observations by Col. Tennant and M. Janssen at Guntoor.—Summary of results.—Observations of Governor J. P. Hennessy and Capt. Reed, R.N.—Eclipse of August* 7, 1869.—*Observations in America by Prof. Morton and others.—Summary of results.—Eclipse of December* 22, 1870. —*English expedition in H. M. S. Urgent to Spain.—Observations in Spain and Sicily.—Eclipse of December* 11, 1871.—*Observed in India.—Eclipse of April* 16, 1874.—*Summary by Mr. W. H. Wesley of the recent observations as to the Physical Constitution of the Corona.*

THE eclipse of the Sun of July 18, 1860, described in the last chapter, may be said to mark a turning-point in the history of eclipse phenomena. It was the first in which photography played a conspicuous part, and the experience acquired by the numerous observers who went to Spain, paved the way for the great photographic and other successes which marked subsequent eclipse expeditions.

The reader who has studied what has been stated in the earlier chapters of this Book, respecting the usual accompaniments of eclipses of the Sun, will already have acquired a sufficiently complete general insight into the subject, and therefore in the present chapter his attention will be mainly invited to new points.

The eclipses which will be grouped together here are the following[a]:—Aug. 18, 1868; Aug. 7, 1869; Dec. 22, 1870; Dec.

[a] A very good general summary of the eclipse observations made in 1868, 1869, and 1870 (accompanied by numerous illustrations) will be found in the English edition of Schellen's *Die Spectralanalyse.* The information relating to the 1870 eclipse is exclusively from English sources drawn upon by the translators. But the most exhaustive account by far is that furnished in *Mem.*

11, 1871; April 16, 1874; April 5, 1875; July 29, 1878; May 17, 1882; May 6, 1883; Sept. 8, 1885; Aug. 29, 1886; Aug. 19, 1887.

To observe the eclipse of 1868, several expeditions were dispatched from Europe to the East Indies. The most important of these was that which under the command of Major Tennant, R.E., went to Guntoor (Lat. 60° 17′ 27″ N., Long. $5^h\ 21^m\ 48^s$ E.); but important service was rendered to Science by a French observer, M. Janssen, who, accompanied by his wife, stationed himself at Guntoor. Another French party, under M. Stéphan, went to Siam, and a German party to Aden. This last-named contingent included MM. Weiss, Oppolzer, and Thiele, all experienced astronomers.

Major Tennant's arrangements were framed with the object of (1) investigating by the aid of a spectroscope the corona and red flames (the latter now very generally called the "Solar prominences"), as regards the source of their light; (2) examining the light of the corona and prominences as regards the polarisation thereof, and (3) obtaining photographs during the totality. By a due subdivision of labour amongst the different members of the expedition this programme was carried to a successful conclusion. Neglecting certain optical effects, common to every total eclipse of the Sun, and sufficiently described already in connection with previous eclipses, I proceed to note briefly, in something like Major Tennant's own words, his deductions as to the new results flowing from the labours of himself and his colleagues [b].

The corona is to be deemed an atmosphere of the Sun, not self-luminous but shining by reflected light. This was proved both by the spectroscope and the polariscope.

During the continuance of the totality, there was seen on the North side of the Sun, an enormous horn of light, the apex of which was calculated to be about 90,000 miles distant from the

R.A.S., vol. xli. 1876. This volume is a magnificent compilation of Eclipse facts. For it science is mainly indebted to Mr. A. C. Ranyard's industry.

[b] *Memoirs* R.A.S., vol. xxxvii. p. 1. 1869.

Sun's limb. This object presented in a striking degree indications of a spiral structure, and was presumed to consist of incandescent vapours of hydrogen, sodium, and magnesium.

Capt. Branfill observed that the corona was strongly polarised everywhere in a plane passing through the Sun's centre.

The general phenomena of the total phase are thus described by Mr. (now Sir J. P.) Hennessy [c]:—

"Ten minutes before the total eclipse there seemed to be a luminous crescent reflected upon the dark body of the Moon. In another minute a long beam of light, pale and quite straight, the rays diverging at a small angle, shot out from the Westerly corner of the Sun's crescent. At the same time Mr. Ellis noticed a corresponding dark band, or shadow, shooting down from the East corner of the crescent. At this time the sea assumed a darker aspect, and a well-defined green band was seen distinctly around the horizon. The temperature had fallen, and the wind had slightly freshened. The darkness then came on with great rapidity. The sensation was as if a thunderstorm was about to break, and one was startled on looking up to see not a single cloud overhead. The birds, after flying very low, disappeared altogether. The dragon-flies and butterflies disappeared, and the large drone-like flies all collected on the ceiling of the tent, and remained at rest. The crickets and Cicadæ in the jungle began to sound, and some birds, not visible, also began to twitter in the jungle. The sea grew darker, and immediately before the total obscuration the horizon could not be seen. The line of round white clouds that lay near the horizon changed their colour and aspect with great rapidity. As the obscuration took place, they all became of a dark purple, heavy looking, and with sharply defined edges; they then presented the appearance of clouds close to the horizon after sunset. It seemed as if the Sun had set at the four points of the horizon. The sky was of a dark leaden blue, and the trees looked almost black. The faces of the observers looked dark, but not pallid or unnatural. The moment of *maximum* darkness seemed to be immediately before the total obscuration; for a few seconds nothing could be seen except objects quite close to the observers. Suddenly there burst forth a luminous ring around the Moon. The ring was composed of a multitude of rays quite irregular in length and in direction; from the upper and lower parts they extended in bands to a distance

Fig. 144.

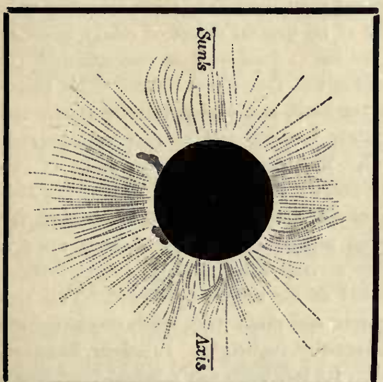


DIAGRAM REPRESENTING THE RAYS OF THE CORONA.
Aug. 18, 1868. (*Hennessy.*)

[c] *Proc. Roy. Soc.*, vol. xvii. p. 84. 1868.

more than twice the diameter of the Sun. Other bands appeared to fall towards one side, but in this there was no regularity, for bands near them fell away apparently towards the other side. When I called attention to this, Lieut. Ray said, 'Yes, I see them; they are like horses' tails;' and they certainly resembled masses of luminous hair in complete disorder. I have said these bands appeared to fall to one side; but I do not mean that they actually fell, or moved in any way, during the observation. If the atmosphere had not been perfectly clear, it is possible that the appearance they presented would lead to the supposition that they moved; but no optical delusion of the kind was possible under the circumstances. During the second when the Sun was disappearing, the edge of the luminous crescent became broken up into numerous points of light. The moment these were gone, the rays I have just mentioned shot forth, and, at the same time, we noticed the sudden appearance of the rose-coloured protuberances. The first of these was about $\frac{1}{8}$ of the Sun's diameter in length, and about $\frac{1}{24}$ of the Sun's diameter in breadth. It all appeared at the same instant, as if a veil had suddenly melted away from before it. It seemed to be a tower of rose-coloured clouds. The colour was most beautiful—more beautiful than any rose-colour I ever saw; indeed, I know of no natural object or colour to which it can be with justice compared. Though one has to describe it as rose-coloured, yet in truth it was very different from any colour or tint I ever saw before. This protuberance extended from the right of the upper limb, and was visible for 6 minutes. In 5 seconds after this was visible, a much broader and shorter protuberance appeared at the left side of the upper limb. This seemed to be composed of two united together. In colour and aspect it exactly resembled the long one. This second protuberance gradually sank down as the Sun continued to fall behind the Moon, and in 3 minutes it had disappeared altogether. A few seconds after it had sunk down there appeared at the lower corresponding limb (the right inferior corner) a similar protuberance which grew out as the eclipse proceeded. This also seemed to be a double protuberance, and in size and shape very much resembled the second one; that is, its breadth very much exceeded its height. In colour, however, this differed from either of the former ones. Its left edge was a bright blue, like a brilliant sapphire with light thrown upon it. Next to that was the so-called rose-colour, and, at the right corner, a sparkling ruby tint. This beautiful protuberance advanced at the same rate that the Sun had moved all along, when suddenly it seemed to spread towards the left until it ran around $\frac{1}{4}$ of the circle, making a long ridge of the rose-coloured masses. As this happened, the blue shade disappeared. In about 12 seconds the whole of this ridge vanished, and gave place to a rough edge of brilliant white light, and in another second the Sun had burst forth again. In the meantime the long rose-coloured protuberance on the upper right limb had remained visible; and though it seemed to be sinking into the Moon, it did not disappear altogether until the lower ridge had been formed, and had been visible for 2 seconds. This long protuberance was quite visible to the naked eye, but its colour could not be detected except through the telescope. To the naked eye it simply appeared as a little tower of white light, standing on the dark edge of the Moon. The lower protuberance appeared to the naked eye to be a notch of light in the dark edge of the Moon—not a protuberance, but an indentation. In shape the long protuberance resembled a goat's horn. . . . Though the darkness was by no means so great as I had expected, I was unable to mark the protuberances in my note-book without the aid of a lantern, which the sailors lit when the eclipse became total. Those who were looking out for stars counted 9 visible to the naked eye; one planet, Venus, was very brilliant. . . . On board the *Rifleman* the fowls and pigeons went to roost, but the cattle showed no signs of uneasiness; they were lying down at the time."

Captain Reed, R.N., remarked as follows respecting the corona:—

"The corona I should not describe as a ring, except in so far as concerned that portion of it immediately surrounding the Moon's limb. From this edge it burst forth in sharp, irregular-shaped masses, of exceedingly bright light, decreasing in brightness as the distance from the Moon increased, and finally resolving into numberless bright rays, the visible extremes of which were distant from two or three diameters of the Moon. The general appearance of the corona, as seen through my glass, struck me forcibly as resembling in form a Brunswick star; the bright light near the Moon resembling the prominent portions immediately surrounding the centre, and the rays the more remote portions. I have heard the appearance described as representing the glory one sees around the heads of saints in old Italian pictures, and to my mind the general appearance could hardly be better described."

The total eclipse of August 7, 1869, was observed by several well-equipped parties in the United States. The American observations were carried out with great skill, and regardless of labour or expense, and resulted in a very complete series of excellent photographs [d]. One of these taken at Ottumwa represents the phenomenon of "Baily's Beads," and is, I believe, the only photographic record of this phenomenon extant. Professor Morton speaks of this as "simply the last glimpse of the Sun's edge cut by the peaks of the Lunar Mountains into irregular spots." The pictures taken during the partial phase all shew an increase of light on the Sun's surface, in contiguity with the Moon's limb, as was observed by De La Rue in 1860. Professor Morton was at first inclined to attribute this to the existence of a Lunar atmosphere; but subsequent experiments have led him to regard the cause as entirely chemical, and not corresponding to any celestial phenomenon. An analogous appearance is frequently to be seen in terrestrial photographs, and it is now generally agreed that the effect is a mere photographic one. Professor Pickering at Mount Pleasant noticed that while "the sky was strongly polarised all round close up to the corona, that

[d] *Report on Observations of the Total Eclipse of the Sun, Aug.* 7, 1869. Edited by Commodore B. F. Sands. 4to. Washington, 1869. *Month. Not.*, vol. xxx. p. 4, Nov. 1869; p. 173, May 1870; *Journal of the Franklin Institute*, 3rd Ser., vol. lviii. pp. 200, 249, and 354, Sept.–Nov. 1869.

object itself was not a source of polarised light." This observation is not in accord with the observations of other eclipses (especially 1842, 1851, 1860, and 1868), for it has always been found that the light of the corona was strongly polarised. Nor indeed do Pickering's observations in 1869 tally with his own conclusions arrived at in 1870 in Spain with superior instruments. His observations in 1869 were made on an unmagnified image of the corona, and his attention was chiefly directed to the polarized condition of the atmosphere. Prof. Pickering is of opinion that his more deliberate observations of the coronal polarization made in 1870 are to be preferred, and that the small apparent size of the corona and its dazzling brightness as seen with the instrument used in 1869 prevented his noticing the polarization colours in the coronal light.

Much more important in every sense than either of the foregoing eclipses, was the eclipse of December 22, 1870. Being visible at some very accessible places in Spain, Sicily, and North Africa, several expeditions were dispatched to observe it, and eventually Her Britannic Majesty's Government placed at the disposal of English astronomers, £2000 and a ship, the *Urgent*, for the conveyance of observers going to Spain and Africa; and the expenses of the party which travelled overland to Sicily were defrayed out of this grant. Besides the observing parties connected with the expeditions just named, a strong detachment of American astronomers, nearly all of them Professors, came to Europe. France was only represented by M. Janssen, for the eclipse occurring towards the end of the Franco-German War, the French had other things to think about. It deserves notice that so great was M. Janssen's anxiety to observe the phenomenon, that he determined upon trying to escape from Paris in a balloon, and succeeded, carrying with him his instruments.

Unfortunately the weather was very unsatisfactory, especially in the North of Africa, where a cloudless sky had been confidently anticipated, and accordingly the successful photographs of Lord Lindsay's party at Cadiz and of the English party at Syracuse, constitute the chief direct results of the efforts made.

The partial failure of the weather is the more to be regretted because the preparations made to observe the eclipse were unusually elaborate and costly, and the services of a particularly strong body of experienced observers had been secured. The general results, though less than had been expected, were undoubtedly of great importance, and constituted a clear advance in our knowledge of Solar physics.

Though attention was paid to other accompaniments of total eclipses of the Sun, and useful confirmatory evidence as to other matters was accumulated, yet the Sun's corona was in 1870 the one main object of attack, and photography, polariscopes, spectroscopes, and ordinary telescopes were all brought to bear on the elucidation of the question "What is the corona?" and important information available for answering the question was obtained.

The next eclipse that was widely observed was that of December 12, 1871, which was visible over a large and accessible tract of country in Southern India, Ceylon, and Australia, though in the last-named part of the world the weather failed. The observations made were as before photographic, spectroscopic, and polariscopic.

It was very generally noticed that the structure of the corona was radiated, and several rifts were seen therein. A comparison of photographs at different stations, indicates a fixity in these rifts which renders it certain that they existed at an immense distance from the observers; in other words, that they were neither terrestrial, nor lunar, but solar.

Fine photographs of the corona in which the definition is very sharp were taken at Baikul by Mr. Davis, Lord Lindsay's photographic assistant, and six photographs on the same scale were taken by Col. Tennant at Dodabetta; and although the dark moon is represented by a circle only $\frac{3}{10}$ of an inch in diameter and the whole extent of the corona could be covered by a sixpence, the definition is so good that on examination under suitable illumination some hundreds of details can be made out and measured, and the two series of photographs are found completely to confirm one another as far as the smallest detail observable. In addition to the corona photographs taken at Baikul and Dodabetta in Central India, two photographs of the corona were secured during this eclipse with an ordinary photographic camera at a station near Tjebatjap in Java; and though these are on a very small scale and the definition does not compare with the Indian photographs, the rifts and some of the larger structures visible in the Indian photographs can be recognized upon them, and as far as they go they show that the corona visible in India was also visible in Java.

The line joining the two most marked rifts which are situated near to the Sun's poles divides the corona into two halves which are roughly symmetrical. The line of symmetry does not accurately coincide with the Sun's axis, but is inclined to it some 10° or 15°. On each side of these polar rifts are groups of incurving structure which occupy an arc of some 40° on the moon's circumference. The curved rays in these groups are all bent inwards, and the straighter rays appear to be inclined from the radial towards parallelism with the axes of the groups.

Within the polar rifts are several narrow straight or but slightly curved rays, none of which are quite radial to the Sun's limb. It is worthy of remark that this inclination to the radial cannot be a mere effect of perspective. For a line passing through the Sun's centre could not be projected so as not to be radial to the Sun's limb. There is abundant evidence that many of the structures visible in other coronas, as well as that observed during the eclipse of 1871, were inclined at considerable angles to the normal to the surface of the photosphere. It is difficult to conceive how explosions within a gaseous body like the sun can give rise to oblique rays, but the evidence for the existence of such rays is overpowering. Some of the oblique rays are straight, or nearly straight, while others shew considerable curvature, and others bend over in one direction in their lower parts, and are again curved slightly in a contrary direction above. Such double curvature, or contrary flexure, is also to be found in some of the tree-like forms of structure which on a gigantic scale remind the observer of a common type of prominence to be seen in the chromosphere.

The existence of these curving forms is a matter of considerable importance, as they appear to indicate the existence of an atmosphere with currents carrying the matter of which the structures are composed, with different velocities at different altitudes. The tree-like structures also seem to indicate the spreading out within a resisting medium of matter rising from below. None of these tree-like structures are to be found in the upper part of the corona, though there are several forked and curving rays whose form it seems difficult to account for by the action of explosive forces and gravity alone. As we proceed towards the outer parts of the corona there are more straight rays, and fewer contorted structures, indicating that the resisting atmosphere in the upper part of the corona is less dense than in the lower. The forms of the structures do not seem to afford evidence of a repulsive force similar to that which drives the matter of a comet's tail away from the Sun, but there are some of them in which the bright coronal matter, after having been driven upwards in an oblique direction, seems to fall again as if by gravity towards the Sun. In most instances however the rays which extend to the outer part of the corona grow gradually fainter in their upper parts without exhibiting any change of direction.

Mr. W. H. Wesley, the Assistant Secretary of the Royal Astronomical Society, who has given great attention to the numerous drawings and photographs of the corona which have been obtained, says[e] :—

"One of the most striking features in the corona of almost all the years under examination is the existence of a more or less well-marked polar rift, roughly, but perhaps never exactly, corresponding with the Sun's axis of rotation, to which it appears sometimes inclined as much as 30°. In most cases this rift is shewn at both poles, but sometimes at one only; in 1882 it does not appear at all. The northern and southern rifts are seldom strictly opposite to one another, so that a line drawn through them does not pass through the centre of the Sun. The polar rifts are

[e] *Month. Not.*, vol. xlvii. p. 500. June 1887.

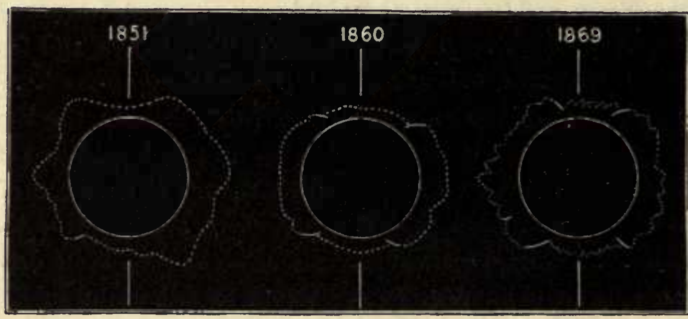
generally filled with shorter, straighter, and more radial rays, with a background of less density than in other parts of the corona.

"On either side of the polar rift there usually appears a somewhat conical mass, composed of rays curving towards each other, forming groups of what Mr. Ranyard has appropriately called 'synclinal structure,' which give the quadrilateral or cruciform appearance frequently shewn in corona drawings. They mostly seem to be situated over the zones of maximum sun-spot activity, and have frequently greater extension than other parts of the corona."

Eclipse of 1851, July 28.

"Dr. Busch's daguerreotype is remarkable as the first instance of a successful photograph of the corona. It shews the general form to a height nowhere much exceeding ¼ of a solar diameter. The corona is symmetrical and of hexagonal form,

Fig. 145.



OUTLINE OF THE CORONA.

with a well-marked rift not far from the north and south poles, the southern rift being much the broader. On either side of these rifts are indications of synclinal masses; there are also similar masses in the equatorial regions fairly corresponding on each side. The orientation of the plate is rather uncertain. Wolf gives 64·2 as the relative number of sun-spots for July 1851."

Eclipse of 1860, July 18.

"In the photographs taken at Desierto de las Palmas, of which I have only seen positive copies, there is shewn a very broad rift towards the south pole, and a less marked one on the north. The character of the synclinal groups is not clearly marked. The corona is fairly symmetrical about a line not much inclined from the Sun's axis. Wolf's relative number of sun-spots is 94·9."

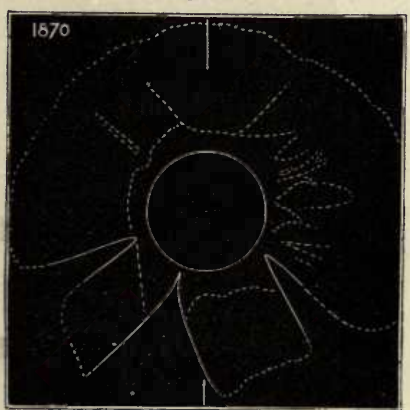
Eclipse of 1869, August 7.

"I have not seen the original negatives of the photographs taken at Shelbyville, which are the only ones which shew any considerable extent of corona. The northern and southern polar rifts are clearly marked and very broad. The bases of the four synclinal groups can also be clearly made out, especially that in the north-west quadrant. The general axis of symmetry is slightly inclined to the north-west and south-east of the Sun's axis. Wolf's relative number of sun-spots is 77·6."

ECLIPSE OF 1870, DEC. 22.

"Mr. Brothers's negative, taken at Syracuse, shews a great extent of corona, reaching in some parts quite 40′ from the limb. The general outline is somewhat circular, with a quadrilateral area of greater brightness, brighter on the western side. The northern polar rift is broad and ill-defined; to the east of the south pole is a much narrower and more sharply defined rift, easily traceable to the limb. To the east and west of this are other rifts, and there is structure evidently synclinal to the north-west; otherwise the photograph shews but little detail. The general axis of symmetry appears inclined to the north-west and south-east of the Sun's axis as much as 20°, but the orientation is not very certain. The eclipse occurred at a period of great solar activity, Wolf's relative monthly number being 135·4."

Fig. 146.



OUTLINE OF THE CORONA, 1870.

ECLIPSE OF 1871, DEC. 12.

"Lord Lindsay's and Col. Tennant's excellent series of negatives shew a corona remarkably symmetrical, about a line inclined about 10° to the north-west and south-east of the Sun's axis. The northern and southern polar rifts are well defined, nearly opposite to one another, and very similar in character. The four synclinal groups are well marked, appearing to indicate zones of synclinal structure extending nearly from the pole to about 40° north and south latitude. These groups are generally separated from the equatorial portions by narrow definite rifts. The western margin of the south-east synclinal group shews a distinct tendency to double curvature—a form which reappears in 1883 and 1885. The extension is greatest in the equatorial regions, giving a somewhat hexagonal form to the corona. The great polar rifts are filled with short straight rays.

"The greatest extent of the photographic corona does not exceed 27′, but the minuteness of the detail near the limb, which with a strong transmitted light can be seen through the densest part of film, has never been equalled in any subsequent eclipse photograph. The remarkable feature of the lower structure is the prevalence of rays completely curving over, and of branching rays, somewhat resembling a frequent form of solar prominence. Few of these reach a height of more than 5′ from the limb; above this height the rays are generally straight or more slightly curved.

"It is impossible to be certain whether these lower details are really near the limb, or whether they are rays on the nearer or further parts of the corona, seen foreshortened. In the latter case, they could hardly be the extreme ends of coronal rays,

Fig. 147.

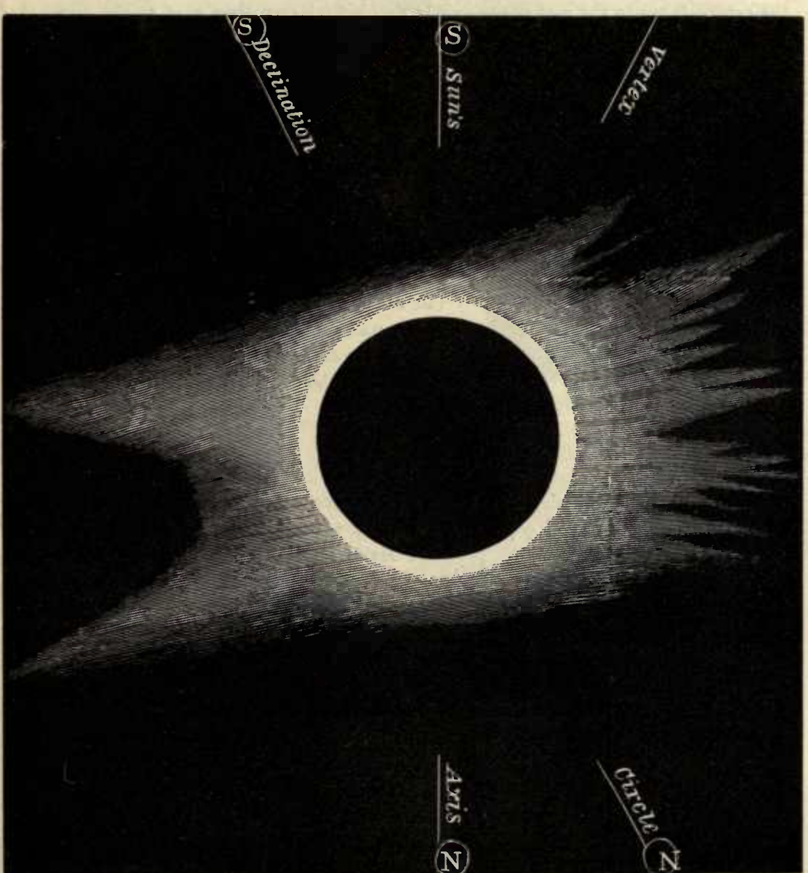
OUTLINE OF THE CORONA, 1871.

as these invariably fade away so much towards their extremities that they would certainly be lost on the dense background. On the whole, the difference of character between the higher and the lower details lends great probability to the view that the latter are really near the limb. Mr. Ranyard considers that the more contorted character of these lower structures indicates the existence of a resisting atmosphere in the lower part of the corona. It seems evident, at least, that many of the curvatures of the coronal rays could not be caused by gravity alone. Still when we consider what an intricate mass of crossing and interlacing rays must be produced by perspective as we approach the limb, we must feel that the question cannot be decided with certainty.

"The eclipse occurred at a time of somewhat less solar activity than that of the previous year, Wolf's relative monthly number being 98·0."

No photographs having been taken of the eclipse of 1874, no annotations on the corona of that eclipse appear in Mr. Wesley's paper. I have however thought it would be well to annex a hand-drawing thereof.

Fig. 148.



THE TOTAL ECLIPSE OF THE SUN OF APRIL 16, 1874.
Naked-eye view of the outer Corona. (*H. E. R. Bright.*)

Mr. Wesley then proceeds to deal with the eclipses subsequent to 1874:—

ECLIPSE OF 1875, APRIL 6.

"The small size of the photographs taken by Dr. Schuster renders it impossible to make out more than the general character of the corona, and from the same cause the orientation is not very accurately determined. The corona is somewhat symmetrical about a line nearly coinciding with the Sun's axis, the northern and southern polar rifts being very broad and well marked. Four synclinal groups are plainly seen, their axes making angles of more than 45° with the Sun's axis. The polar rifts are filled up, but not to a great height, the polar extension of the corona being only about half the equatorial, where the greatest height is nearly a solar diameter. The half of the corona lying to the east of the axis is decidedly larger than that to the west, so that the nearly straight lines which bound the corona north and south converge towards the west. Dr. Schuster draws attention to the remarkable similarity between this corona and that of 1874, of which no photographs were taken. He thinks this similarity extends to the irregularity in the symmetry just mentioned; but the want of accordance between the drawings made in 1874 renders this uncertain.

Fig. 149.

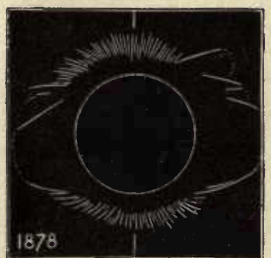
OUTLINE OF THE CORONA, 1875.

"Notwithstanding this general resemblance, the solar activity, as indicated by the sunspots, was less than half as great as in the previous year, Wolf's relative number for April 1874 being 49·1, and for April 1875 20·5."

Eclipse of 1878, July 29.

"The photographs which I have examined are two negatives by Mr. Ranyard, made at Denver, and a series of 9 positive copies on glass of the photographs taken by Professor Harkness and Mr. Rogers at Creston and La Junta. The exposures of Mr. Ranyard's plates were so short that they show but a small extent of corona. A drawing combining the detail of the Creston and La Junta negatives, and shewing a further extension of the equatorial rays, from a smaller photograph by Mr. Peers, is given in the *Appendix to the Washington Observations* for 1876. On comparing this drawing with the positives, it does not seem very satisfactory. I can make out as much or more detail on the positives as on the drawing (except the equatorial extension), and no doubt much more would be seen on the original negatives.

Fig. 150.



OUTLINE OF THE CORONA, 1878.

"The corona belongs to the same type as those of 1874 and 1875. The equatorial extension greatly exceeds the polar, and both the northern and southern rifts are widely opened, so that their eastern and western boundaries form nearly straight lines tangential to the limb. The northern and southern synclinal groups are so much depressed towards the equator that they appear to coalesce into one great mass, occupying the whole equatorial region. The rifts are filled with fine rays, straight, and nearly radial in the centre of the rift, and becoming more and more curved towards its boundaries. In one rift there are as many as 20 separate rays, remarkably uniform in length and distance apart, never branching or crossing. The two rifts are almost identical in character, but are not opposite each other; the northern rift having its general axis inclined about 15° towards the east from the Sun's axis, and the southern being more symmetrical with it.

"The great equatorial extensions, of which the bases only are visible in the positives, are very symmetrical in detail, but the western mass is the broader, reaching further both to the north and south. These great masses are broadest near the limb, and gradually become narrower, so that their northern and southern boundaries would meet in a point about 2 diameters from the limb on the western side, and rather less on the eastern. These equatorial extensions were, however, observed by Newcomb, Langley, and others, to reach to a distance of at least 12 diameters. They must have been very faint, as in the American drawing, combined from various negatives, they do not extend more than a diameter.

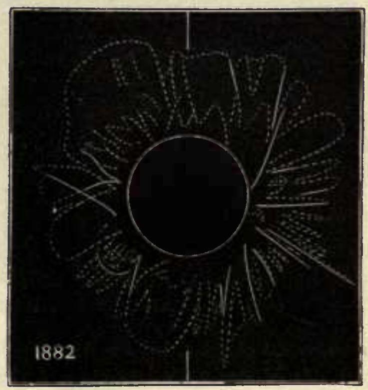
"It is a remarkable peculiarity, which I have observed in no other corona, that while at the poles it is split up into a great number of fine rays, the equatorial extensions are broad smooth masses, shewing scarcely any detail, even at their extreme edges.

"The eclipse occurred at a time of decidedly low solar activity, Wolf's relative number being only 3·3."

ECLIPSE OF 1882, MAY 17.

"The negatives taken by Dr. Schuster shew a large extent of corona, reaching in several places a height of a solar diameter, one straight ray in the south-west extending as far as $1\frac{1}{4}$ diameter. The corona presents none of the features which characterised those of 1874, 1875, and 1878. Although very irregular in detail, it is approximately circular in form, and is entirely without that great difference between the polar and equatorial extensions which had been so striking in the three last eclipses. At the same time it shews none of that symmetry about a line not very far from the Sun's axis that had been more or less apparent in most previously photographed coronas, and especially in that of 1871. This absence of an axis of symmetry and of polar rifts is its most striking feature. There are groups of synclinal structure, but they are not of a very definite character, and are quite irregularly placed. The solar axis does not pass through the line of least extension, as is almost always the case. The only approach to an axis of symmetry seems to be about a line nearly at right angles with the Sun's axis. The orientation was, however, very carefully made, and in Dr. Schuster's opinion is not more than half a degree in error: it nearly agrees with that adopted by Professor Tacchini.

Fig. 151.



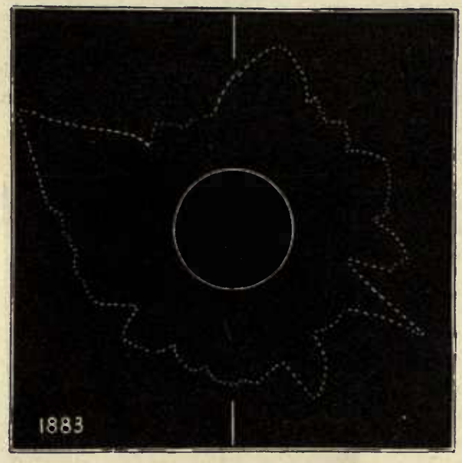
OUTLINE OF THE CORONA, 1882.

"The rays are rather more frequently straight than curved, and there is only one instance of a ray completely curving over: this is in the south-east; it reaches a height of about 12′ from the limb. Beneath it are two rays—the only ones shewing any traces of a branching structure. There are distinct rifts on the western side, reaching to the limb; but they are more filled up with coronal matter than those of 1871. The rays are in all directions, from radial to tangential, and there are several cases of rays crossing each other, but no clear case of a ray of double curvature. The lower details of the corona are less distinct than in 1871; but this may be due to the great density of the film near the limb, which is common to all dry-plate negatives. The definition of the outer portions is extremely fine. I cannot see any evidence of the distinction between an outer and inner corona, which Dr. Schuster thinks the photographs shew. Wolf's relative monthly number of sun-spots is 64·5; a remarkable outburst had occurred during the preceding month, for which the number was 95·8."

Eclipse of 1883, May 6.

"Successful photographs were taken by M. Janssen, and also by Messrs. Lawrance and Woods. The most prominent feature is an unusually well-marked rift, partly filled with short straight rays, near the north pole of the Sun's axis, from which the general axis of the rift is inclined at an angle of about 30° to the east. On each side of this rift are most characteristic groups of synclinal structure, whose bases meet at the limb: the easternmost shews a double curvature on both sides, but on the western edge this appearance seems caused by the superposition of different rays. There seems no regularity in the arrangement of the rays in the rest of the corona, nor any rift in the south, corresponding to that in the north. The general outline of the corona is somewhat circular, but the two synclinal groups extend farther than any other part. In M. Janssen's long-exposed plate, one of these groups extends nearly as far as two solar diameters, which is the greatest extension shewn by any corona photograph. Indeed, M. Janssen says that it is much greater than it appeared to the eye in his telescope.

Fig. 152.



OUTLINE OF THE CORONA, 1883.

"The solar activity was rapidly decreasing, Wolf's relative monthly number of sun-spots being 32·1."

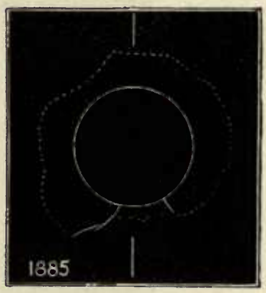
Eclipse of 1885, September 8.

"Several photographs were taken of this eclipse, but the weather was generally unfavourable, and few shew much detail. The most marked feature is the southern rift, which is broad and well marked, with clear indications of straight rays filling it. The only distinctly synclinal group is to the south-east; its axis makes an angle of about 45° with the Sun's axis, and its extension is greater than any other part of the corona. The western edge of this group presents a double curvature. The other parts of the corona are very irregular, and there does not appear to be any distinct rift on the north corresponding with the southern rift. There is a marked broad depression in the corona, about 35° to the east of the north point of the axis. This depression, and the southern rift, appear to divide the corona into two very unequal parts, the western one being much the greater.

"The solar activity, as shewn by the sun-spots, was diminishing; Wolf's relative monthly number being 83·7 for the month of June, and 39·6 for September.

"The only generalisation with regard to the form of the corona which has seemed well supported by the photographic evidence is that of Mr. Ranyard, that there is a connection between the general form of the corona and the solar activity as shewn by the number of sun-spots. The corona of a sun-spot maximum has generally been somewhat symmetrical, with synclinal groups making angles of 45° or less with its general axis. The sun-spot minimum coronas shew polar rifts much more widely open, synclinal zones making larger angles with the axis, and being therefore more depressed toward the equatorial regions, in which there is usually greater extension. This generalisation is well borne out by the maximum coronas of 1870 and 1871 and the minimum coronas of 1867, 1874, 1875, 1878, and apparently 1887. On the other hand, the eclipses of 1883, 1885, and 1886, do not strikingly confirm the theory. The eclipse of 1883, at a time of rapidly decreasing solar activity, shews all the characters of a sun-spot maximum corona; the same in a somewhat less degree may be said of 1885 and 1886, at both of which times the solar activity was decreasing. Although the polar rifts were wide in 1886, there was no very marked depression of the synclinal groups towards the equator, nor any great equatorial extension, although the relative number of sun-spots for August 1886 was only 19·0. Striking, therefore, as the evidence in favour of the generalisation has been in many years, it still seems probable that the form of the corona is modified by other causes at present unknown to us."

Fig. 153.



OUTLINE OF THE CORONA, 1885.

ECLIPSE OF 1886, AUGUST 29.

"Good photographs were taken at Grenada by Mr. Maunder, Dr. Schuster, and Prof. W. H. Pickering. The northern and southern rifts are fairly symmetrical about the Sun's axis, and are very wide. The synclinal groups bounding the rifts are well-marked, but very unsymmetrical, being depressed towards the equator on the eastern side, while the corresponding groups on the west are nearly radial. The south-west synclinal group is narrow and conical, extending to a greater height than any other part of the corona. On the eastern side the coronal extension is generally less than on the western, and the mass of equatorial rays on the east is of much less breadth, and is synclinal in character. The separation between the southern synclinal groups and the equatorial rays is unusually well-marked. Both polar rifts are filled with fine rays of the same character as the polar rays in 1878, but somewhat less regular.

"One of Pickering's negatives shews very remarkable rays on the western side, extending to a height of 60′ from the limb, and curving completely over. These are by far the highest rays of this character that have ever been photographed. On this

Fig. 154.

OUTLINE OF THE CORONA, 1886.

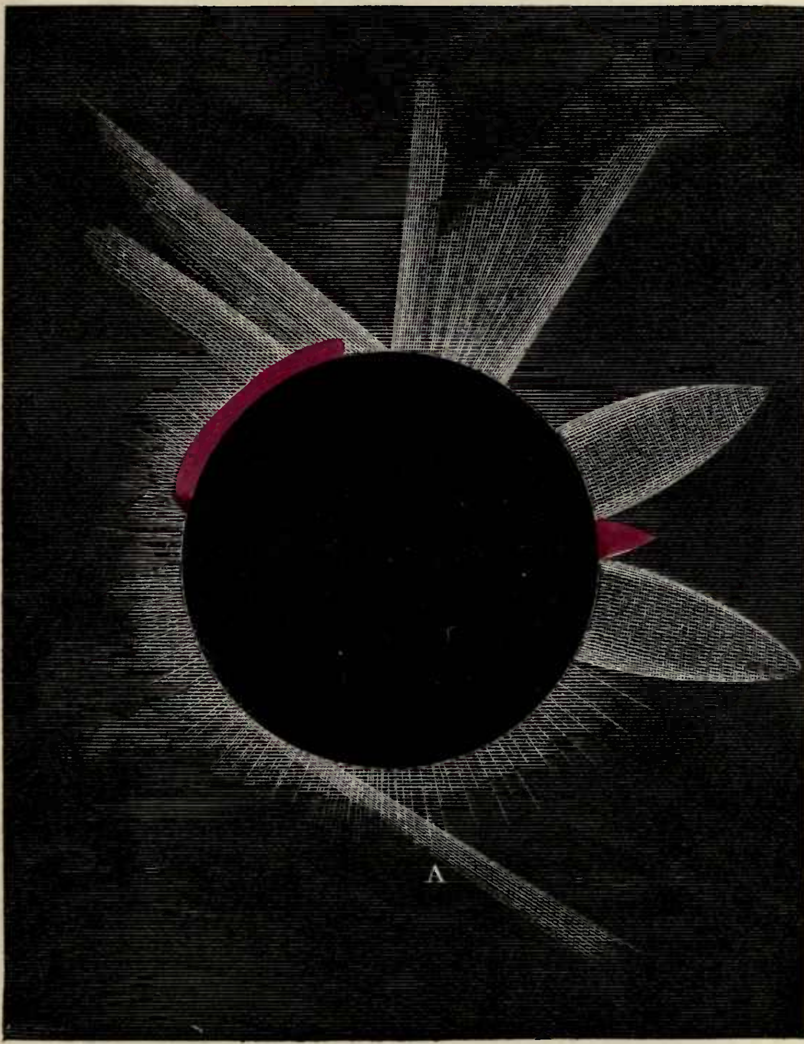
account they are of great interest if they are genuine coronal features, but Prof. Pickering can only detect them on one of his plates, and this was taken on a very small scale. Wolf's relative monthly number of sun-spots was 19·0."

Eclipse of 1887, August 19.

"The extremely unfavourable weather which prevailed over Europe greatly interfered with the observations, and seems to have prevented successful photographs being taken at any of the Russian Stations. A hand-drawing of the corona, made in Siberia by Dr. Khandrikoff, is given on Plate XXI. Successful photographs, of which positive copies have been sent to England, were made by M. Sugiyama in Japan. Judging from these copies, the corona somewhat resembles that of 1878, but the peculiar characters of that year are less strongly marked in 1887. The rifts are more widely open than in 1886, and the masses of rays bounding the rifts are more depressed towards the equator. The northern rift is filled with regular rays like the polar rays of 1878, but in the southern rift are broader, denser, and nearly radial masses, giving quite a different character to this part of the corona. Synclinal groups, separated from the general mass of equatorial rays, bound the southern rift, but cannot be clearly made out in the north. Wolf's relative number of sun-spots for August was 21·1, but the mean number for the year was less than that for 1886."

Fig. 155.

OUTLINE OF THE CORONA, 1887.



THE TOTAL ECLIPSE OF THE SUN OF AUG. 19, 1887.
(*Khandrikoff.*)

CHAPTER VII.

HISTORICAL NOTICES[a].

Eclipses recorded in Ancient History.—Eclipse of 584 B.C.—*Eclipse of* 556 B.C.—*Eclipse of* 479 B.C.—*Eclipse of* 430 B.C.—*Eclipse of* 309 B.C.—*Allusions in old English Chronicles to Eclipses of the Sun.*

THE earliest eclipse on record is one given in the Chinese history named the *Chou-king*; it has been supposed that a solar eclipse happened on Oct. 13, 2128 B.C.[b], and that that is the one there alluded to. What happened in connection with it was this, though I cannot vouch for the details. Ho and Hi the Astronomers Royal of the period failed to give timely warning of the eclipse, but got drunk instead. The eclipse happened therefore without the proper religious preparations having been made, and the land was exposed to the anger of the gods. To appease them the officials in question were forthwith executed. If this is fact and not romance, the record is a very interesting one, contemporaneous as it is with the Patriarchs of the Bible.

One of the most celebrated eclipses of the Sun recorded in history is that which occurred in the year 585 B.C. It is notable, not only on account of its having been predicted by Thales, who was the first ancient astronomer who gave the true explanation of the phenomena of eclipses, but because it seems to fix the precise date of an important event in ancient history. Herodotus

[a] See the Rev. S. J. Johnson's *Eclipses past and future.* The fullest general account of all the early eclipses of importance is that which will be found in S. Newcomb's *Researches on the Motion of the Moon,* Part I, "Observations on the Moon before 1750," pp. 27–54 (Washington, 1878).

[b] *Mem.* R.A.S., vol. xi. p. 47. 1840.

describes a war that had been carried on for some years between the Lydians and the Medes; and gives an account of the following circumstances which led to its premature termination:—

"As the balance had not inclined in favour of either nation, another engagement took place in the 6th year of the war, in the course of which, just as the battle was growing warm, day was suddenly turned into night (*συνήνεικε ὥστε τῆς μάχης συνεστεώσης τὴν ἡμέρην ἐξαπίνης νύκτα γενέσθαι*). This event had been foretold to the Ionians by Thales of Miletus, who predicted for it the very year in which it actually took place. When the Lydians and Medes observed the change they ceased fighting, and were alike anxious to conclude peace." Peace was accordingly agreed upon and cemented by a twofold marriage. "For without some strong bond, there is little security to be found in men's covenants."

So adds the historian[c]. The exact date of this interesting event was long disputed, and the solar eclipses of 610, 593, and particularly 585 B.C., were each fixed upon as the one mentioned by Herodotus; and it is only within the last few years that the point has been finally settled in favour of the last-mentioned eclipse, and that chiefly through the researches of Sir G. B. Airy, who gives, as the date of the eclipse in question, May 28, 585 B.C.[d] This is reconcileable with the statements of Cicero and Pliny.

Another important ancient eclipse is that mentioned by Xenophon, in the *Anabasis*, as having led to the capture by the Persians of the Median city Larissa. In the retreat of the Greeks on the eastern side of the Tigris, not long after the seizure of their commanders, they crossed the river Zapetes, and also a ravine, and then came to the Tigris. At this place, according to Xenophon, there stood—

"A large deserted city called Larissa, formerly inhabited by the Medes; its wall was 25 feet thick, and 100 feet high; its circumference 2 parasangs; it was built of burnt brick on an understructure of stone 20 feet in height. When the Persians obtained the empire from the Medes, the king of the Persians besieged the city, but was unable by any means to take it till a cloud having covered the Sun and caused it to disappear completely, the inhabitants withdrew in alarm, and thus the city was captured[e]."

[c] Herod., lib. i. cap. 74.

[d] *Phil. Trans.*, vol. cxliii. pp. 191–197. 1853. *Month. Not.*, vol. xviii. p. 143. Mar. 1858.

[e] *Anab.*, lib. iii. cap. 4. § 7.

The historian then goes on to say that the Greeks in continuing their march, passed by another ruined city named Mespila. The minute description given by Xenophon enabled Layard, Felix Jones, and others, to identify Larissa with the modern Nimrud, and Mespila with Mosul. It has been thought that the phenomenon to which the Greek author refers as having led to the capture of the above-mentioned city, was no other than a total eclipse of the Sun, and Airy arrived at the conclusion that the eclipse referred to is that which occurred on May 19, 557 B.C.[f]

In the same year as that in which, according to the common account, the battle of Salamis was fought (480 B.C.), there occurred a phenomenon which is thus adverted to:—

"At the first approach of spring the army quitted Sardis, and marched towards Abydos; at the moment of its departure the Sun suddenly quitted its place in the heavens and disappeared (ὁ ἥλιος ἐκλιπὼν τὴν ἐκ τοῦ οὐρανοῦ ἕδρην ἀφανὴς ἦν), though there were no clouds in sight, and the sky was quite clear; day was thus turned into night (ἀντὶ ἡμέρης τε νὺξ ἐγένετο)[g]."

This account, interpreted as a record of a total solar eclipse, has given great trouble to chronologers, and it is still uncertain to what eclipse reference is made. If Hind's theory that the eclipse of Feb. 17, 478 B.C. is the one referred to, is sound, we must consider that the battle of Salamis is an event less remote by 2 years than has usually been supposed. Airy "thinks it extremely probable" that the narrative relates to the total eclipse of the *Moon*, which happened 478 B.C., March 13^d 15^h G.M.T.[h]

A total eclipse of the Sun, supposed to have been that of August 3, 431 B.C., nearly prevented the Athenian expedition against the Lacedæmonians, but a happy thought occurring to Pericles, commander of the forces belonging to the former nation, the difficulty was got over.

"The whole fleet was in readiness, and Pericles on board his own galley, when there happened an eclipse of the Sun. The sudden darkness was looked upon as an

[f] *Month. Not.*, vol. xvii. p. 234. June 1857. Newcomb doubts this being an eclipse at all. And see a letter by Lynn in *Observatory*, vol. vii. p. 380. Dec. 1884.

[g] Herod., lib. vii. cap. 37. Plutarch, *Pelopidas*, 31. Diod. Sic., lib. xv. cap. 80. Grote, *Hist. of Greece*, vol. x. p. 424.

[h] *Phil. Trans.*, vol. cxliii. p. 197. 1853. See also Blakesley's *Herod.*, *in loco*, and some criticisms by Lynn in *Observatory*, vol. vii. p. 138, May 1884.

unfavourable omen, and threw the sailors into the greatest consternation. Pericles observing that the pilot was much astonished and perplexed, took his cloak, and having covered his eyes with it, asked him if he found anything terrible in that, or considered it as a bad presage? Upon his answering in the negative, he said, 'Where is the difference, then, between this and the other, except that something bigger than my cloak causes the eclipse[i]?'"

Thucydides says:—

"In the same summer, at the beginning of a new lunar month (at which time alone the phenomenon seems possible), soon after noon the Sun suffered an eclipses; it assumed a crescent form, and certain of the stars appeared: after a while the Sun resumed its ordinary aspect[k]."

An ancient eclipse, known as that of Agathocles, has also been investigated by Sir G. B. Airy, and previously by Baily. It took place on August 14, 310 B.C. This eclipse is, according to ancient writers, associated with an interesting historical event. Agathocles, having been closely blockaded in the harbour of Syracuse by a Carthaginian fleet, took advantage of a temporary relaxation in the blockade, occasioned by the absence of the enemy in quest of a relieving fleet, and quitting the harbour of Syracuse, he landed on the neighbouring coast of Africa, at a point near the modern Cape Bon, and devastated the Carthaginian territories. It is stated that the voyage to the African coast occupied 6 days, and that an eclipse (which from the description was manifestly total) occurred on the 2nd day. Diodorus Siculus says that the stars were seen[l], so that no doubt can exist as to the totality of the eclipse. Baily, however, found that there existed an irreconcileable difference between the calculated path of the shadow and the historical statement, a space of about 180 geographical miles appearing between the most Southerly position that can be assigned to the fleet of Agathocles and the Northerly limit of the phase. "To obviate this discordance, it is only necessary to suppose an error of about 3′ in the computed distances of the Sun and Moon at conjunction, a very inconsiderable correction for a date anterior to the epoch of the Tables by more than 21 centuries[m]."

[i] Plutarch, *Vita Periclis.*

[k] Thucyd., lib. ii. cap. 28.

[l] Diodor. Sic., lib. xx. cap. 1. Justin., lib. xxii. cap. 6.

[m] *Phil. Trans.*, vol. cxliii. pp. 187–191. 1853.

In the work mentioned in the note below[n] there will be found an extremely interesting epitome of all the discussions which have taken place respecting the Eclipses of the Sun of 610, 603, 585, 557, and 310 B.C., together with charts of the tracks of the shadow on each occasion. The writer, the late Mr. J. W. Bosanquet, F.R.A.S., also brings out very clearly the way in which these eclipses are available for settling points of chronology.

In the writings of the early English chroniclers are to be found numerous passages relating to total eclipses of the Sun. The eclipse of August 2, 1133, was considered a presage of misfortune to Henry I.: it is thus referred to by William of Malmesbury:—

"The elements manifested their sorrow at this great man's last departure. For the Sun on that day at the 6th hour shrouded his glorious face, as the poets say, in hideous darkness, agitating the hearts of men by an eclipse; and on the 6th day of the week, early in the morning, there was so great an earthquake that the ground appeared absolutely to sink down; an horrid noise being first heard beneath the surface[o]."

The same writer, speaking of the total eclipse of March 20, 1140, says:—

"During this year, in Lent, on the 13th of the calends of April, at the 9th hour of the 4th day of the week, there was an eclipse, throughout England, as I have heard. With us, indeed, and with all our neighbours, the obscuration of the Sun also was so remarkable, that persons sitting at table, as it then happened almost everywhere, for it was Lent, at first feared that Chaos was come again: afterwards learning the cause, they went out and beheld the stars around the Sun. It was thought and said by many, not untruly, that the king [Stephen] would not continue a year in the government[p]."

[n] *Messiah the Prince, or the Inspiration of the Prophecies of Daniel.* 2nd ed., 8vo. Lond. 1869.

[o] *Hist. Nov.*, lib. i.

[p] *Hist. Nov.*, lib. ii. See also *Sax. Chron.*, Thorpe's Trans., p. 233. 8vo. London, 1861.

CHAPTER VIII.

ECLIPSES OF THE MOON.

Lunar Eclipses of less interest than Solar ones.—Summary of facts connected with them.—Peculiar circumstances noticed during the Eclipse of March 19, 1848.—*Observations of Forster.—Wargentin's remarks on the Eclipse of May* 18, 1761.—*Kepler's explanation of these peculiarities being due to Meteorological causes.—Admiral Smyth's account of the successive stages of the Eclipse of Oct.* 13, 1837.—*The Eclipse of Jan.* 28, 1888.—*The Eclipse of Sept.* 2, 1830, *as witnessed in Africa by R. and J. Lander.—Chaldæan observations of Eclipses.—Other ancient Eclipses.—Anecdote of Columbus.*

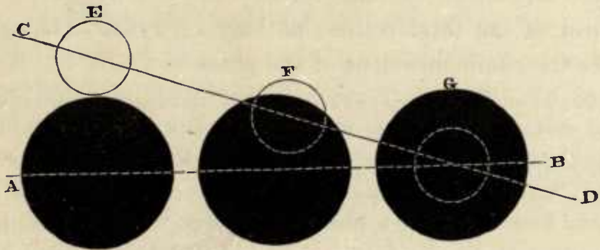
AN eclipse of the Moon, though inferior in importance in all senses to one of the Sun, is nevertheless by no means devoid of interest; it is either partial or total[a], according to the extent to which our satellite is immersed in the Earth's shadow. In a total eclipse the Moon may be deprived of the Sun's light for $1^h\ 50^m$, and reckoning from the first to the last contact of the penumbra, the phenomenon in its various stages may last $5^h\ 30^m$, but this is the outside limit. The obscuration is found to last longer than calculation assigns to it. This is due to the fact that no account is taken in the calculations of the denser strata of the atmosphere through which the rays have to pass, which cause an obstructive effect analogous to that of the solid matter of the Earth. From numerous observations made during the eclipse of Dec. 26, 1833, Beer and Mädler found that the apparent breadth of the shadow was increased by $\frac{1}{50}$ on account of the terrestrial atmosphere. "Owing to the ecliptic limits of the Sun

[a] But never annular, because the diameter of the Earth's shadow, at the greatest possible distance of the Moon from the Earth, is always in excess of the diameter of the lunar disc.

exceeding those of the Moon, there are more eclipses of the former luminary than of the latter; but on account of the comparatively small extent of the Earth's surface to which a solar eclipse is visible, the eclipses of the Moon are more frequently seen at any particular place than those of the Sun."

Fig. 157 is designed to illustrate roughly the different conditions of eclipses of the Moon. A B is the ecliptic, C D the Moon's path. The 3 black circles are imaginary sections of the Earth's shadow, when in 3 successive positions in the ecliptic. If the

Fig. 157.



CONDITIONS OF ECLIPSES OF THE MOON.

conjunction in longitude of the Earth and Moon occurs when the Moon is at E, it escapes eclipse; if the Moon is at F, it suffers a *partial* obscuration, but if the Moon is at or very near its node, indicated by G, it will be wholly involved in the Earth's shadow and a *total* eclipse will be the result.

Whereas solar eclipses always begin on the Western side and go off on the Eastern, lunar eclipses on the contrary commence on the Eastern side and go off on the Western.

Even when most deeply immersed in the Earth's shadow, our satellite does not, except on rare occasions, wholly disappear, but may be generally detected with a telescope (and frequently with the naked eye), exhibiting a dull red or coppery colour. This was exemplified in a very remarkable manner in the case of the eclipse of March 19, 1848, on which occasion the Moon was seen so clearly that many persons doubted the reality of the eclipse.

Mr. Forster, who observed the eclipse at Bruges, writes as follows:—

"I wish to call your attention to the fact which I have clearly ascertained, that during the whole of the late eclipse of March 19, the shaded surface presented a luminosity quite unusual, probably about three times the intensity of the mean illumination of the eclipsed lunar disc. The light was of a deep red colour. During the totality of the eclipse, the light and dark places on the face of the Moon could be almost as well made out as on an ordinary dull moonlight night, and the deep red colour where the sky was clearer was very remarkable from the contrasted whiteness of the stars. My observations were made with different telescopes; but all presented the same appearance, and the remarkable luminosity struck every one. The British Consul at Ghent, *who did not know there was an eclipse*, wrote to me for an explanation of the blood-red colour of the moon at 9 o'clock [b]."

As a complement to this observation, I may quote one by Wargentin of the total eclipse of May 18, 1761. He says that 11^m after the commencement of the phase—

"The Moon's body had *disappeared so completely, that not the slightest trace of any portion of the lunar disc could be discerned either with the naked eye or with the telescope*, although the sky was clear, and the stars in the vicinity of the Moon were distinctly visible in the telescope [c]."

The red hue was long a phenomenon for which no explanation could be found; by some it was considered to be due to a light naturally inherent to the Moon's surface, but Kepler was the first to offer a more scientific explanation. He shewed that the phenomenon was a direct result of the refraction of the Earth's atmosphere, which had the effect of turning the course of the solar rays passing through it, causing them to fall upon the Moon even when the Earth was actually interposed between them and the Sun. That the colour of the Moon's surface is red is due to the fact that the blue rays of light are absorbed in passing through the terrestrial atmosphere, in the same manner as the Western sky is frequently seen to assume a ruddy hue when illuminated in the evening by the solar rays. On account of the variable meteorological condition of our atmosphere the quantity of light actually transmitted is liable to considerable fluctuations,

[b] *Month. Not.*, vol. viii. p. 132. Mar. 1848.

[c] *Phil. Trans.*, vol. li. p. 210. 1761. The original runs thus: "Tota luna ita prorsus disparuerat, ut nullum ejus vestigium, vel nudis, vel armatis oculis, sensibile restaret, cœlo licet sereno, et stellis vicinis in tubo conspicuis." Other eclipses, where the same thing occurred, took place on June 15, 1620 (Kepler, *Epist. Ast.*, p. 825); April 25, 1642 (Hevelius, *Selenog.*, p. 117); and June 10, 1816 (Beer and Mädler).

and hence arises a corresponding variation in the appearances presented by the Moon's surface during her immersion in the Earth's shadow. If the portion of the atmosphere through which the solar rays have to pass is everywhere tolerably free from vapour, the red rays will be almost wholly absorbed, but not so the blue, and the illumination will be too feeble to render the Moon's surface visible : as in the instances cited in note [c], p. 328. If, on the other hand, the region of the atmosphere through which the solar rays pass be everywhere highly saturated, the red rays will be transmitted to the Moon in great abundance, and its surface will consequently be highly illuminated [d]. Such was the case in the eclipse of March 1848 already referred to. If, moreover, the region of the atmosphere through which the rays pass be saturated only in some parts and not in others, it follows that some portions of the Moon's disc will be invisible whilst others will be more or less illuminated. Such an occurrence was seen by Kepler [e] on Aug. 16, 1598, and by Sir J. Herschel and Smyth on Oct. 13, 1837.

Smyth has recorded what he saw at each stage of this eclipse and it is worth while to give his account [f], with the sketch which accompanies it, for the two together will serve as a model for observers desirous of knowing how to record the progress of an eclipse of the Moon.

"22^h 55^m 0^s. A light grey penumbra appearing.

"22^h 55^m 40^s. The Moon suffused with a copper tint.

"22^h 57^m 12^s. The dark shadow impinged on the lunar limb, and gradually marched over Grimaldus (*a*).

"23^h 1^m 17^s. Touched the crater of Aristarchus, the shadow filling the valleys as it advanced, then ascending the hills, and extinguishing their bright summits (*b*).

"23^h 13^m 25^s. Reached the fine regions of Copernicus, part of the cloud to the South crossing Gassendus. The stars gradually increasing in brightness (*c*).

"23^h 32^m 38^s. Across the lunar disc, and through the streaky range of Tycho. Darkness increased so as to show the Milky Way (*d*).

"23^h 44^m 47^s. The umbra passed the rugged mountains of Theophilus, soon after which sea-green tints were observable (*e*).

[d] Johnson does not consider that these explanations accord with the observed meteorological facts. (*Month. Not.*, vol. xlv. p. 44. Nov. 1884.) Monck takes the same view, and it is not open to doubt that the whole question needs more investigation and discussion.

[e] *Ad Vitell. Paralipom.*

[f] *Cycle of Celest. Obj.*, vol. i. p. 144.

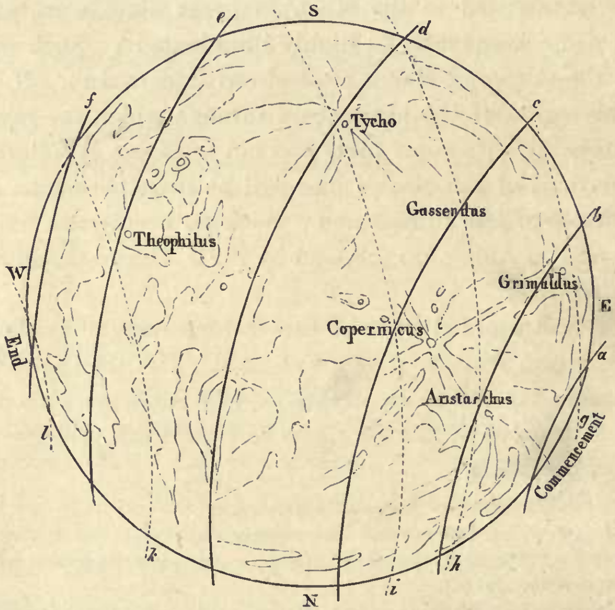
" $23^h\ 54^m\ 10^s$. The shadow became more transparent, and the whole orb visible, so that the spots and other particulars of the selenography were revealed (*f*).

" $0^h\ 8^m\ 8^s$. The sea-green tint spread all over the Moon. A star nearly in a line with Aristarchus and Copernicus, close to the moon's limb, was occulted 25^s afterwards.

" $0^h\ 22^m\ 40^s$. The moon became lighter all over. Perhaps the retina of the eye had been fatigued by the lunar brightness at first, and was now awakening to delicate impressions.

" $0^h\ 58^m\ 40^s$. The shadows seemed to be of a dark neutral tint, diluted in its intensity by refracted light; a streak of sea-green towards Aristarchus. Turned the

Fig. 158.



ECLIPSE OF THE MOON, OCT. 13, 1837.

telescope upon the nebula 76 Messier, as a gauge, and saw it beautifully; but it gradually faded as the Moon emerged.

" $1^h\ 28^m\ 21^s$. While the experiments were being made on nebula, during the total obscuration, the green tints were displaced by the copper ones, and a silvery light appeared over Grimaldus (*g*).

" $1^h\ 40^m\ 29^s$. Aristarchus became uncovered, and its brightness rendered the obscured part more opaque (*h*).

" $1^h\ 52^m\ 12^s$. Copernicus and Tycho uncovered. The smaller stars retiring and all of them dimming (*i*).

" $2^h\ 20^m\ 58^s$. Theophilus re-appeared almost in full splendour. The nebula 76 Messier only perceptible from a knowledge of its form and place (*k*).

"$2^h\ 29^m\ 30^s$. The small obscured segment of a curious dark tint, lessening with a smooth motion (*l*).

"$2^h\ 31^m\ 4^s$. The shadow entirely left the moon, and the eclipse terminated. The smaller stars vanished, and none but the more brilliant visible. The moon as splendid as ever."

The Rev. Canon Beechey writing of the eclipse of Oct. 4, 1884, mentions that during totality the Moon presented "one equal flat tint of cold grey, through which every feature of the lunar surface was distinctly visible;" and that the eclipse generally was "remarkably similar to the one described by Smyth" as having happened on Oct. 13, 1837.

The following account of the eclipse of Jan. 28, 1888, will be found to present several points of interest[g]:—

"The phase of total eclipse began nominally at 10.30 G. M. T., but it was not until fully 20 minutes after this that the last remains of the silvery shading along the west limb of the Moon had entirely disappeared. Up till the time that it did disappear the familiar coppery hue often seen in total eclipses of the Moon was not at all uniformly spread over the Moon's disc; indeed there was no more than a coppery patch somewhat to the east of the centre of the disc for a long time, and I doubted whether this usual concomitant of a lunar total eclipse was going to be at all a conspicuous feature. However, as time wore on and the middle of the eclipse drew near, the whole disc (at 11.20) became overspread with the coppery hue. I speak of it under this name because it is the term usually employed, but in reality the tinge was more pink than coppery in the usual sense of the word, and it was much paler than usual; so much so indeed that in the middle of the totality (at 11.30) it was easy enough not only to see the whole disc of the Moon but also to identify some of the more conspicuous craters, such as Tycho, Copernicus, and Kepler, as well as several of the larger 'seas.'

"By 11.37 a further change of aspect had manifested itself, and a silvery hue had begun to appear on the east limb much sooner than one would have expected in the ordinary course of things.

"During the next 10 minutes a further enfeeblement of the pink hue took place more or less all round the margin of the disc, with the result that the Moon (looked at with the naked eye) presented an appearance scarcely different from that which she oftens presents during a common London fog.

"At 11.55, a small star which had been occulted by the Moon reappeared, and its pure white light offered a curious contrast to the muddy pink of the Moon.

"Soon after this the atmosphere began to get hazy all round, and before the total phase ended (at 12.10) the pink hue had become greatly enfeebled, though it did not finally disappear for a considerable time—half an hour or more.

"The haze varied much from minute to minute, and every now and then, when a little denser, its effect on the Moon was to make her look like a perfect snowy sphere, and her globular form was brought out with intense reality, constituting a sight of remarkable beauty."

[g] Letter in the *Times*, Jan. 31, 1888. (G.F.C.)

The celebrated African explorers, the Landers, graphically describe what took place on the occasion of the eclipse of the Moon of Sept. 2, 1830. They say:—

"The earlier part of the evening had been mild, serene, and remarkably pleasant. The Moon had arisen with uncommon lustre, and being at the full, her appearance was extremely delightful. It was the conclusion of the holidays, and many of the people were enjoying the delicious coolness of a serene night, and resting from the laborious exertions of the day; but when the Moon became gradually obscured, fear overcame every one. As the eclipse increased they became more terrified. All ran in great distress to inform their sovereign of the circumstance, for there was not a single cloud to cause so deep a shadow, and they could not comprehend the nature or meaning of an eclipse....Groups of men were blowing on trumpets, which produced a harsh and discordant sound; some were employed in beating old drums; others again were blowing on bullocks' horns....The diminished light, when the eclipse was complete, was just sufficient for us to distinguish the various groups of people, and contributed in no small degree to render the scene more imposing. If a European, a stranger to Africa, had been placed on a sudden in the midst of the terror-struck people, he would have imagined himself to be among a legion of demons, holding a revel over a fallen spirit [h]."

It is to the Chaldæans that we owe the earliest recorded observations of lunar eclipses, as mentioned by tolemy. The first of these took place in the 27^{th} year of the era of Nabonassar, the first of the reign of Mardokempadius, on the 29^{th} day of the Egyptian month *Thoth*, answering to March 19, 720 B.C., according to our mode of reckoning. It appears to have been total at Babylon, the greatest phase occurring at about $9^h\ 30^m$ P.M. The second was a partial eclipse only; it happened at midnight on the 18^{th} of the month *Thoth*, or on March 8, 719 B.C. The third took place in the same year, on the 15^{th} of the month *Phammuth*, or Sept. 1, 719 B.C. The magnitude of the eclipse, according to Ptolemy, was 6 digits on the southern limb, and it lasted 3 hours, having commenced soon after the Moon rose at Babylon.

Three eclipses recorded by Ptolemy and which happened in 523, 502, and 491 B.C., assisted Sir I. Newton in ascertaining the *terminus a quo* from which the "70 weeks" of years were to be calculated which the prophet Daniel (ix 24) predicted were to precede the death of Christ. And this *terminus a quo* is on good

[h] R. and J. Lander, *Journal of an Expedition to explore the Niger*, vol. i. p. 366, New York, 1844.

grounds considered to have been the restoration of the Jews under Artaxerxes in his 7th year (457 B.C.)[i].

An eclipse occurred in the 4th year of the 91st Olympiad, the 19th of the Peloponnesian war, answering to Aug. 27, 412 B.C., which produced very disastrous consequences to the Athenian army, owing to the obstinacy of their general Nicias[j]. Modern calculations shew that it was total at Syracuse.

The eclipse of the Moon which happened on March 13, 4 B.C., serves to determine the date of our SAVIOUR'S birth. This event preceded, by a few weeks, the death of Herod, and, according to Josephus[k], that occurrence took place soon after a lunar eclipse which has been identified as stated[l]. The Nativity took place in the Autumn or Winter of 5 B.C.

An eclipse of the Moon, which happened on March 1, 1504, proved of much service to Columbus[m]. His fleet was in great straits, owing to the want of supplies, which the inhabitants of Jamaica refused to give. He accordingly threatened to deprive them of the Moon's light, as a punishment. His threat was treated at first with indifference, but when the eclipse actually commenced, the natives, struck with terror, instantly commenced to collect provisions for the Spanish fleet, and thenceforward treated their visitors with profound respect.

[i] H. G. Guinness, *Approaching end of the Age*, 5th ed., p. 516: J. B. Lindsay, *Chrono-Astrolabe*, Lond., Bohn, pp. 75 *et seq*.

[j] Plutarch, *Vita Nicias*. Thucyd., lib. vii. cap. 50.

[k] *Antiq.*, xvii. 4.

[l] See Wieseler, *Chronological Synopsis of the* 4 *Gospels*, p. 51. I cannot see the force of the Rev. S. J. Johnson's reasoning in favour of the eclipse of Jan. 9, 0 B.C. (*Eclipses, past and present*, p. 21.)

[m] W. Robertson, *Hist. of America* 10th ed., vol. i. book ii. p. 240.

CHAPTER IX.

A CATALOGUE OF ECLIPSES[a].

THE eclipses visible in England have received much attention from the Rev. S. J. Johnson, and papers of his cited below will be interesting to many English readers[b].

The following Catalogue contains all the eclipses which occur during the remainder of the 19th century, excepting solar eclipses hardly visible to any inhabited portion of the Earth, and lunar eclipses in which less than $\frac{1}{10}$ of the Moon's diameter is obscured. The time is approximately that of Greenwich, M. standing for morning, and A. for afternoon. Under the head of "Locality" the letter **C** points to the path followed by the central line; in cases where this passes very near the North or South Pole, it is not traced, but those places only are named where the eclipse will be visible (**V**). The letters N.E. or S.E. following the name of a place, indicate the direction taken by the shadow after passing the parts in question.

[a] For Catalogues of Eclipses extending over long periods of time see Oppolzer's *Canon der Finsternisse* in *Denkschriften der Kaiserlichen Akad. der Wissenschaften*, vol. lii. Vienna 1887; and *L'Art de vérifier les dates*, Paris 1818, vol. i. p. 269.

In connection with the calculation of Solar eclipses attention may here be called to a very interesting memoir by S. Newcomb, *On the recurrence of Solar Eclipses, with Tables of Eclipses from* B.C. 700 to A.D. 2300; in *Astronomical Papers for the use of the American Ephemeris and Nautical Almanac*, vol. i. Washington, U.S., 1879.

[b] *Month. Not.*, vol. xxxiii. p. 402, Ap. 1873: Ib. vol. xl. p. 436, May 1880.

Year.		Month and Day.	Hour.	Magnitude.	Locality.
1889	☉	Jan. 1	9 A.	...	C Behring's Straights; Nootka; Hudson's Bay.
—	☾	Jan. 17	5½ M.	0·68	United States.
—	☉	June 28	9 M.	...	C S. Africa; Magagascar, S.E.
—	☾	July 12	9 A.	0·46	Armenia.
—	☉	Dec. 22	1 A.	...	C Carthagena; St. Helena; Abyssinia.
1890	☉	June 17	10 M.	...	C Cape Verde Islands; Smyrna; Pegu.
—	☉	Dec. 12	3 M.	...	C Mauritius; New Zealand; Tahiti.
1891	☾	May 23	7 A.	1·31	India.
—	☉	June 6	4½ A.	...	C N.W. America; N. Pole; Russia.
—	☾	Nov. 16	0½ M.	1·44	Ireland.
1892	☉	April 26	10 A.	...	C S. Pacific.
—	☾	May 11	11¼ A.	0 94	France.
—	☉	Oct. 20	7 A.	...	V N. America.
—	☾	Nov. 4	4½ A.	1·04	China.
1893	☉	April 16	3 A.	...	C Easter Island; Guiana; N.E. Africa.
—	☉	Oct. 9	9 A.	...	Sandwich Islands; Peru.
1894	☾	Mar. 21	2½ A.	0·25	New Guinea.
—	☉	April 6	4½ M.	...	C Egypt; China; Pacific.
—	☾	Sept. 15	4½ M.	0·21	Canada.
—	☉	Sept. 29	5½ M.	...	C Madagascar; New South Wales; New Zealand.
1895	☾	Mar. 11	4 M.	1·56	Barbados.
—	☉	Mar. 26	10 M.	...	V Atlantic; Europe; N. Asia.
—	☉	Aug. 20	0½ A.	...	V N. Asia.
—	☾	Sept. 4	6 M.	1·54	Mississippi.
1896	☾	Feb. 28	8 A.	0·83	E. Persia.
—	☉	Aug. 9	4½ M.	...	C Prussia; E. Siberia; Pacific.
—	☾	Aug. 23	7 M.	0·66	New Mexico.
1897	☉	Feb. 1	8 A.	...	C New Caledonia; Easter Is.; Guiana.
—	☉	July 29	4 A.	...	C Gallipagos; Barbados; Guiana.
1898	☾	Jan. 7	Midnt.	0·12	London.
—	☉	Jan. 22	8 M.	...	C Fezzan; Socotra; N. China.
—	☾	July 3	9½ A.	0·92	Russia.
—	☉	July 18	7 A.	...	V S. America.
—	☾	Dec. 27	Midnt.	1·33	London.
1899	☉	Jan. 11	11 A.	...	V E. Asia; N. America.
—	☉	June 8	7 M.	...	V N. Europe; N. Asia.

Year.		Month and Day.	Hour.	Magnitude.	Locality.
1899	☾	June 23	2½ A.	1·50	New Guinea.
—	☾	Dec. 17	1½ M.	0·96	Cape Verde Islands.
1900	☉	May 28	3 A.	...	C Mexico; Azores; Egypt.
—	☉	Nov. 22	8 M.	...	C Benin; Madagascar; New South Wales.

According to Hind[c] the following are the important total eclipses of the Sun for the remainder of the present century, which are likely to be available for increasing our knowledge of solar physics:—Dec. 22, 1889, the totality of which lasts for $3^m\ 34^s$, and April 19, 1893, lasting $4^m\ 44^s$.

[c] *Month. Not.*, vol. xxxii. p. 178 (Feb. 1872).

CHAPTER X.

TRANSITS OF THE INFERIOR PLANETS.

Cause of the phenomena.—Lord Grimthorpe's statement of the case.—Long intervals between each recurrence.—Useful for the determination of the Sun's parallax.—List of transits of Mercury.—Of Venus.—Transit of Mercury of Nov. 7, 1631.—*Predicted by Kepler.—Observed by Gassendi.—His remarks.—Transit of Nov.* 3, 1651.—*Observed by Shakerley.—Transit of May* 3, 1661.—*Transit of Nov.* 7, 1677.—*Others observed since that date.—Transit of Nov.* 9, 1848.—*Observations of Dawes.—Of Forster.—Transit of Nov.* 11, 1861.—*Observations of Baxendell.—Transit of Nov.* 5, 1868.—*Transit of May* 6, 1878.—*Transit of Nov.* 7, 1881.—*Summary by Jenkins of the main features of a Transit.—Observations by Prince.—By Langley.—Transit of Venus of Nov.* 24, 1639.—*Observed by Horrox and Crabtree.—Transit of June* 5, 1761.—*Transit of June* 3, 1769.—*Where observed.—Singular phenomenon seen on both occasions.—Explanatory hypothesis.—Other phenomena.—Transit of Dec.* 8, 1874.—*Transit of Dec.* 6, 1882.

WHEN an inferior planet is in inferior conjunction, and "has a [geocentric] latitude, or distance from the ecliptic, less than the Sun's semi-diameter, it will be less distant from the Sun's centre than such semi-diameter, and will therefore be within the Sun's disc. In this case the planet being between the Earth and the Sun, its dark hemisphere being turned towards the Earth, it will appear projected upon the Sun's disc as an intensely black round spot. The apparent motion of the planet being retrograde, it will appear to move across the disc of the Sun from E. to W. in a line sensibly parallel to the ecliptic." Such a phenomenon is called a *transit*, and as it can only occur in the case of inferior planets it is limited to Vulcan (if there be such a planet), Mercury, and Venus. Observations of these planets—or rather, in practice, of Venus only—are available for determining the parallax of the Sun, from which may be found the distance of the Earth from that luminary[a].

The *rationale* of the process is thus popularly set forth by Lord Grimthorpe:—"If two men stand before a post with a wall behind it, they will see different places on the wall eclipsed or hidden by the post; and if the post is as far from the two eclipsed places as it is from the men, the two eclipses will be exactly as far apart as the two men are; if the wall is twice as far from the post, the two eclipses will be twice as far apart, and so on.

"Therefore two people on the Earth, as far apart as they can conveniently get for them both to see the transit of Venus from beginning to end, will see at the same time the two transit spots twice and a half as far apart in real distance on the Sun as the observers are distant from each other. Suppose they are 7200 miles apart (measuring through the Earth the shortest way) then the two transit spots will be 18,000 miles apart on the Sun; and we have only one step more to take in order to find the diameter of the Sun in miles; and that is, to get an accurate map made of the disc of the Sun with the exact positions of the two spots at the same time; for then we can measure their distance on the map and see what proportion it bears to the diameter, and we know that 18,000 miles bears that same proportion to the real diameter of the Sun, and the business is done.

"The real difficulty is to get this Sun-map made accurate enough to measure from, or to get the exact distance of the spots at the same moment, remembering that the two observers are nearly half way round the Earth from each other. For that purpose the following contrivance is adopted. Instead of observing the transit at one moment only, each man observes the whole path of Venus across the Sun; or rather in reality he observes the exact time it takes; for they can observe the first and last contact of the spot far more accurately than they can

[a] For a somewhat full account of the principles which underlie the various methods and of the scientific value of the various results hitherto accomplished see a paper by W. Harkness, *Amer. Journ. Sc.*, vol. xxii. p. 375, Nov. 1881; also an *Address* by the same, *Proceedings of the American Association for the Advancement of Science*, vol. xxxi. Aug. 1882.

measure distances on the bright face of the Sun; and it is not necessary that they should see anything but the beginning and the end of the transit. The places on the Earth are so chosen that the paths may appear not only parallel, but at the widest distance possible apart, forming two chords across the Sun, parallel to the diameter which Venus would pass along if she was exactly in the ecliptic and seen from the centre of the Earth. The two paths may be on different sides of the Sun's centre if Venus is exactly at a node, but they are more likely to be on the same side, in which case their difference of length is greater, and the observations more likely to give an accurate result.

"For the accuracy of the map depends on this: you have a circle of known diameter to start with, because the time Venus would take to cross the middle of the Sun is known from the proportion which his diameter bears to the orbit of Venus, and the time she takes to perform it. So if that time were known to be 6 hours we might draw a circle of 6 inches diameter for the Sun; and if one observer reported his transit to have lasted 5 hours we should find the place where a chord 5 inches long will exactly fit; and if the other transit lasted $5\frac{1}{4}$ hours, we should put in another chord $5\frac{1}{4}$ inches long, parallel to and near the former. (The real lengths could not be exactly these, but that does not signify.) The distance between two chords of 5 and $5\frac{1}{4}$ inches in a circle 6 inches wide can be calculated with the utmost accuracy, and also the proportion of that distance to the diameter, which is the proportion of the 18,000 miles to the real diameter of the Sun, the thing we wanted.

"I have said nothing about the rotation of the Earth during the time the transit lasts; but of course due allowance has to be made for that by methods known to astronomers[b]."

James Gregory (the inventor of the "Gregorian" Telescope) seems to have been the first to point out this application of planetary transit observations[c].

[b] *Astron. without Mathematics*, 3rd ed., p. 185.

[c] *Optica Promota*, p. 130. For a lucid account of the method see Airy's *Lectures on Astronomy*, p. 145.

The transits of the inferior planets are phenomena of very rare occurrence, especially those of Venus, which occur only at intervals of 8, 105½, 8, 121½, 8, 105½, &c. years. Transits of Mercury usually happen at intervals of 13, 7, 10, 3, 10, 3, &c. years. This, however, is not altogether a correct expression of the intervals; for, owing to the considerable inclination of Mercury's orbit, it requires a period of about 217 years to bring the transits round in a completely regular cycle.

The following are the dates of the transits of Mercury and Venus from the beginning of the 19th century onwards[d]:—

Mercury.		d.	h.	Venus.		d.	h.
1802	November ...	8	20	1874	December ...	8	16
1815	November ...	11	14	1882	December ...	6	4
1822	November ...	4	14	2004	June	7	21
1832	May	5	0	2012	June	5	13
1835	November ...	7	7	2117	December ...	10	15
1845	May	8	8	2125	December ...	8	3
1848	November ...	9	1	2247	June	11	0
1861	November ...	11	19	2255	June	8	16
1868	November ...	4	18	2360	December ...	12	13
1878	May	6	6	2368	December ...	10	2
1881	November ...	7	2	2490?	June	12	3
1891	May	9	14	2498	June	9	20
1894	November ...	10	6	2603	December ...	15	12

The transits of Mercury, owing to the heliocentric position of the nodes, always happen in May or November. When the transit occurs in May, the planet is passing through the *descending node*, and when in November, through the *ascending node*. Similar remarks apply to the transits of Venus, the only difference being that the months are June and December.

[d] Lalande, *Astron.*, vol. ii. pp. 457–61. Lalande's original Table gives for Venus the transits up to A.D. 2984—some time hence! For transits of Mercury 1891–2108 see *Astron. Papers for use of American Nautical Almanack*, Ed. by S. Newcomb, vol. i. part vi. Washington, 1882. This memoir contains an extremely exhaustive discussion of all the mathematical questions which arise in connection with Transits of Mercury, based on past records and on theory.

The shortest transit of Mercury yet observed was that of Nov. 12, 1782. It lasted only $1^h\ 14^m$. The longest, that of May 6, 1878, lasted for $7^h\ 47^m$. The average duration is about 4^h.

The first observed transit of Mercury occurred on November 7, 1631, and was predicted by Kepler[e], whose surmise was verified by Gassendi at Paris. The latter remarks:—

"The crafty god had sought to deceive astronomers by passing over the Sun a little earlier than was expected, and had drawn a veil of dark clouds over the Earth, in order to make his escape more effectual. But Apollo, acquainted with his knavish tricks from his infancy, would not allow him to pass altogether unnoticed. To be brief, I have been more fortunate than those hunters after Mercury who have sought the cunning god in the Sun; I found him out, and saw him where no one else had hitherto seen him[f]."

The second observed transit of this planet happened on Nov. 3, 1651. It is chiefly interesting to us from the fact that it was observed by a young Englishman, Jeremiah Shakerley; who, having found by calculation that the phenomenon would not be visible in England, went out to Surat in India for the purpose of witnessing it[g].

The third observed transit took place on May 3, 1661. It was observed in part by Huygens, Street, and Mercator in London, and by Hevelius at Dantzic. The last-named astronomer was astonished to find that the angular diameter of the planet was so small[h]: his determination of it agrees well with modern results.

The fourth observed transit occurred on Nov. 7, 1677, and is noticeable from the fact that it was the first which was watched throughout (by Halley) from ingress to egress.

The transits at which anything of particular interest was noticed are the following:—

Transit of Nov. 3, 1697. Wurzelbau, at Erfurt, perceived a strange greyish-white spot on the dark body of the planet.

Transit of Nov. 11, 1736. Plantade remarked that the disc of the planet appeared surrounded by a luminous ring.

Transit of May 7, 1799. Schröter and Harding observed the

[e] *Admonitio ad Astronomos*, &c.

[f] *Opera Omnia*, vol. ii. p. 537.

[g] Wing, *Astronomia Britannica*, p. 312.

[h] *Mercurius in Sole visus*, p. 83.

luminous halo seen by Plantade in 1736, and they likewise saw two greyish spots on the planet when on the Sun. They ascribed to them a motion corresponding to the rotation they subsequently inferred from other observations. The halo or ring was of a darkish tinge, approaching to violet.

Transit of Nov. 9, 1802. Fritsch and others saw a greyish spot.

Transit of May 5, 1832. Moll, of Utrecht, saw a ring encircling the planet when on the Sun, and also a spot on the planet's disc. The ring had something of a violet tinge. Two spots were seen by Harding, and Gruithuisen thought he saw one.

Concerning the transit of Nov. 8, 1848, Dawes, who observed it at Cranbrook in Kent, says:—

"Nothing remarkable was noticed till Mercury had advanced on the Sun's disc to about three-quarters of its own diameter, when the cusps appeared much rounded off, giving a pear-shaped appearance to the planet. The *degree* of this deformity, however, *varied* with the steadiness and definition of the Sun's edge, being least when the definition was *best*. A few seconds before the complete entrance of the planet, the Sun's edge became much more steady, and the cusps sharper, though still occasionally a little broken towards their points by the undulations. At the instant of their junction, the definition was pretty good, and they formed the finest conceivable line, Mercury appearing at the same time *perfectly round*. . . . No difference is recognised in the *Nautical Almanac* between the polar and equatorial diameters of this planet; yet my observations, both with the 5-foot achromatic and the Gregorian, shew a perceptible difference, and nearly to the same amount. . . . The compression would appear to be about $\frac{1}{29}$ [i]."

Forster observed the transit at Bruges. He remarked the extreme *blackness* of the planet compared with the spots: the ratio of the intensities he estimated at 8 : 5. He also stated that the planet had rather the appearance of a *globe* than of a *disc*, and the difference of blackness between the planet and the spots was less remarkable when he used a reflector with a red shade [k].

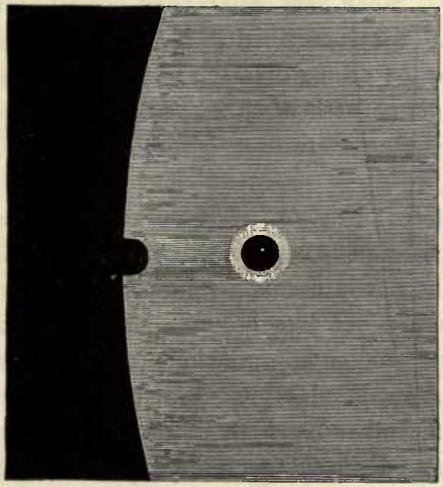
A transit happened on Nov. 11, 1861. In England few observations were made, owing to unfavourable weather. Mr. Baxendell, of Manchester, remarked the excessive blackness of the planet as compared with the nuclei of certain solar spots, and

[i] *Month. Not.*, vol. ix. p. 21. Dec. 1848.
[k] *Month. Not.*, vol. ix. p. 4. Nov. 1848.

that the planet's contour became pear-shaped immediately before the egress[l].

The transit of Mercury which happened on Nov. 5, 1868, was visible in England. Important observations were made by Huggins[m]. An aureola of light around the planet and a luminous point of light on the body of the planet "nearly in the centre" were seen, and thus previous observations were fully confirmed. The breadth of the luminous annulus was about ⅓ of the planet's apparent diameter. There was no fading off at the margin, the

Fig. 159.



MERCURY DURING ITS TRANSIT, NOV. 5, 1868.

brightness being everywhere about the same, and only slightly in excess of that of the general surface of the Sun. Both the aureola and the luminous spot were visible throughout the whole transit.

Huggins's account of what he saw towards the end of the phenomenon is as follows :—

"The following appearance was noticed almost immediately after the planet's disc came up to the Sun's limb. The spot appeared distorted, spreading out to fill up partly the bright cusps of the Sun's surface between the planet's disc and the Sun's

[l] *Month. Not.*, vol. xxii. p. 43. Dec. 1861.

[m] *Month. Not.*, vol. xxix. p. 25. Nov. 1868.

limb. This appearance increased as the planet went off the Sun, until when the disc of the planet had passed by about one-third of its diameter, it presented the form represented in the diagram, in which the margin of the disc from points at the end of a diameter parallel to the Sun's limb, instead of continuing its proper curve, appeared to go in straight lines up to the limb, thus entirely obliterating the cusps of light, which would otherwise have been seen between the planet and the limb. In the diagram the aureola and the bright spot are not repeated in the figure of the planet on the Sun's limb."

The transit of May 6, 1878 was observed under such discouraging circumstances of weather that a very brief allusion to the results [n] will suffice. Several observers saw a minute bright spot or patch on the planet, and several observers saw no such spot or patch. Some saw what they described as a "ring"; some saw what they described as a "halo"—encompassing the disc of the planet; others detected no such phenomenon. Some who noticed one or both of these things confess to a suspicion that spot and ring were merely optical effects, or effects of contrast.

The transit of Nov. 7, 1881 was well seen at several stations in Asia and Australia [o]. Tebbutt at Windsor, New South Wales, saw at intervals a faint whitish spot which at one instant lengthened out into a streak across the disc. He considered the phenomenon an optical one not in any way connected with the planet itself. He looked for but failed to see any halo or ring. On the other hand Dr. Little at Shanghai states that the planet was "always surrounded by a darkish halo, which seemed well defined, extending to a distance about equal to the planet's semi-diameter. With no power could any spots on the planet be detected."

Jenkins, collecting and comparing all the results recorded up to 1868, considered himself justified in advancing the following propositions:—

1st. That in the May transits, when Mercury is near its aphelion, the luminous spot is in advance of the planet, preceding the centre; in the November transits, when Mercury is near its perihelion, the luminous spot follows the planet.

[n] *Month. Not.*, vol. xxxviii. p. 397. May 1878.

[o] *Month. Not.*, vol. xlii. p. 101, &c. Jan. 1882.

2nd. The luminous spot has never been seen at the centre, but always south of it, and therefore cannot be due to diffraction.

3rd. Sometimes in the same transit two spots have been seen close together, where shortly before only one was observed.

4th. In the May transits the rings round the planet are dark or nebulous and of a violet tinge; in the November transits they are bright.

5th. If we take the two transits which have received the most careful observation, May 1832, observed by Moll, and November 1868, observed by Huggins, we find the contrast very great and very typical: in the one case a diffused spot preceding the centre, with dark ring surrounding the planet; in the other a sharply defined spot following the centre, with bright ring surrounding the planet[p].

The annulus round Mercury and the white spot on Mercury during transits across the Sun may now be regarded as regular concomitants of the phenomenon, but there is no agreement amongst astronomers as to the cause of these appearances. The white spot has been regarded by some as indicative of Volcanic action, but this seems mere fancy. Prof. Powell, with more show of reason, suggested that diffraction of light had something to do with the matter, but it is an objection to this theory that it presupposes the invariable centrality of the white spot; now the white spot, though often, is not always coincident in position with the centre of the planet's disc, and therefore Huggins rejects the hypothesis. It might conceivably have its origin in the internal reflection of light in a Huygenian Eye-piece.

We now come to the transits of Venus[q], which are more important and more rare. In the year 1627 Kepler completed the *Rudolphine Tables*, and being thus in a position to calculate the motions of the planets with far more certainty than had ever been attained before, he betook himself diligently to the work.

[p] *Month. Not.*, vol. xxxviii. p. 337. Ap. 1878.

[q] Previous to the transit of 1878 Lord Lindsay put forth in conjunction with Dr. R. Copeland an exhaustive paper of *Notes and Suggestions to Observers.* These should be consulted by persons proposing to conduct observations of future transits, but this will be a matter for many generations hence.

The first result was, that he ascertained that during 1631 both Mercury and Venus would traverse the Sun's disc, the former on Nov. 7 and the latter on Dec. 6; which information he published in a little tract in 1629[r]. Of the transit of Mercury I have already spoken. With reference to that of Venus, Gassendi made preparations for observing it; and though Kepler's calculations were to the effect that the ingress would not take place till near sunset, the French astronomer, anticipating the possibility of the calculated times being too late, (as had been the case with Mercury a few weeks previously,) prepared to commence his watch on Dec. 4, though bad weather prevented him seeing the Sun till the 6th. He sought unsuccessfully for the planet both on that and on the following day, and it is now well known that the transit took place on the night of Dec. 6—7.

The next transit of Venus (the first actually observed) took place on Nov. 24, 1639 (o. s.) Kepler did not anticipate it, for he said that none would take place between 1631 and 1761, and so the honour both of predicting and of observing it rests with a young English amateur, the Rev. Jeremiah Horrox, curate of Hoole, a village in Lancashire, 20 miles N. of Liverpool. Horrox had been engaged in computing the places of the planets by the aid of Lansberg's Tables. Finding that these gave very erroneous results he discarded them for Kepler's, from which he found that on the above named Nov. 24, Venus, in passing its inferior conjunction, would cross the heavens a little *below* the Sun. As Lansberg's Tables indicated that the planet would cross the upper part of the solar disc, he hoped that a mean of the two results, so to speak, might be looked for, and that he should see the planet actually *on* the Sun, towards the lower extremity of its disc: further calculation assured him that his anticipation would turn out to be correct. Owing to the shortness of the interval that would elapse previous to the actual occurrence of the transit he was unable to give much publicity

[r] *Admonitio ad Astronomos rerumque celestium studiosos, de miris rarisque anni* 1631 *Phænomenis, Veneris puta et Mercurii in Solem incursu.* Lipsiæ, 1629.

to the result at which he had arrived; indeed all that he seems to have done was to inform his brother Jonas of Liverpool and his friend William Crabtree, an enthusiastic amateur like himself, who resided at Broughton, near Manchester, not many miles distant from Hoole.

Horrox prepared to watch for the planet by transmitting the image of the Sun through a telescope on to a screen in a darkened room. His final calculations gave 3^h P.M. on Nov. 24 as the time of conjunction of the centres of the Sun and planet; but fearing to be too late, he commenced his scrutiny of the Sun on Nov. 23. On the following day he began his observations at Sunrise, and continued them till the hour of Church service. (It was Sunday.) As soon as he was again at leisure—that is to say at 3^h 15^m P.M.—he resumed his labours, and, to quote his own words, "At this time an opening in the clouds, which rendered the Sun distinctly visible, seemed as if Divine Providence encouraged my aspirations; when, O most gratifying spectacle! the object of so many earnest wishes, I perceived a new spot of unusual magnitude, and of a perfectly round form, that had just wholly entered upon the left limb of the Sun, so that the margin of the Sun and spot coincided with each other, forming the angle of contact." Owing to the near approach of Sunset, Horrox was unable to observe the planet longer than half an hour; but at any rate he had seen it, and had been able to take some measurements [s].

Crabtree had also made arrangements for observing the phenomenon. The Sun was, however, obscured during the whole of the day, and he had given up in despair all hope of seeing the transit, when, just before Sunset, the clouds broke up, and, hastening to his observing chamber, he saw, to his infinite delight, Venus depicted on the Sun's disc transmitted on to a screen. He was, according to his own account, so entranced by the spectacle that ere he recovered his self-possession the clouds had again enshrouded the Sun, and he saw the planet no more.

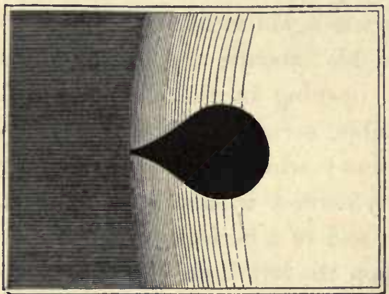
[s] Whatton, *Memoir of Horrox*, pp. 109—135. See also an article in the *Observatory*, vol. vi. p. 318, Nov. 1883.

He subsequently found that a rough diagram, which he drew from memory, agreed well with one drawn by Horrox.

No other transit occurred till June 5, 1761: this was observed in many parts of the world for the purpose of ascertaining, in accordance with the special suggestion of Halley, the solar parallax. But the results of the different observations were not satisfactory.

Extensive preparations were made for observing the transit of June 3, 1769, and King George III. despatched, at his own expense, a well-equipped expedition to Tahiti under the command of the celebrated navigator Cook, then a Lieut., R. N. Many of the Continental Powers followed the example of England, and astronomers were sent out to the most advantageous points for observation. The chief of these were St. Petersburg, Pekin, Orenburg, Iakutsk, Manilla, Batavia, for the egress; and Cape Wardhus, Kola and Kajeneburg in Lapland, Point Venus in Tahiti, and Fort Prince of Wales and St. Joseph in California, for the entire phenomenon. The observations were long looked upon as trustworthy, but astronomers eventually came to the conclusion that an important correction in the final result must be accepted[t]. Accordingly, the transits of Dec. 9, 1874 and Dec. 6, 1882 were awaited with special eagerness.

Fig. 160.



VENUS DURING ITS TRANSIT IN 1769.

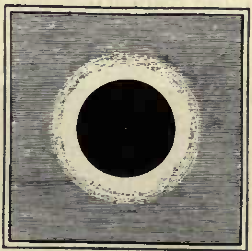
Some phenomena were seen in connexion with the transits of 1761 and 1769 which require a passing mention. It was noticed on both occasions, and by numerous observers, that the interior contact of the planet with the Sun did not take place regularly at the ingress, but that the planet appeared for a short time after

[t] See p. 2 *ante*.

it had entered upon the disc of the Sun to be attached to the Sun's limb by a dark ligament. A similar phenomenon was noticed at the egress. It was also found that even after the planet had got wholly clear of the Sun's limb it did not acquire circularity for several seconds[u]. Lalande suggested[x] that irradiation was the cause of these phenomena, and this is doubtless the true explanation.

It was remarked by several observers of the transits of 1761 and 1769, that, both at the ingress and egress, the portion of the limb of the planet which was not then projected on the Sun was rendered perceptible by reason of a faint ring of light which surrounded it. More than one observer noticed a ring round Venus when it was entirely *within* the disc of the Sun, similar, it would seem, to that which has been seen to surround Mercury when in the same situation. Dunn stated that this annulus had a breadth of 5″ or 6″, that it was somewhat dusky towards the limb of the planet, and that its outer margin was slightly tinged with blue. Hitchins described it as excessively white and faint, and brightest towards the body of the planet. Nairne spoke of it as brighter and whiter than the body of the Sun. A comparison of the different accounts seems to shew that the above-described rings are *not* identical, but no sufficient explanation has been offered to account for either, though the latter has been supposed to indicate the existence of an atmosphere around the planet[y].

Fig. 161.



VENUS DURING ITS TRANSIT IN 1769.

One observer of the transit of 1769 is stated to have seen a light on the disc possibly similar to that occasionally noticed on Mercury during its transits[z].

[u] See *Phil. Trans.*, 1761, 1768, 1769, 1770: also *Mém. Acad. des Sciences* for the same years.

[x] *Mém. Acad. des Sciences*, 1770, p. 409.

[y] For references for all these statements, see Grant's *Hist. of Phys. Ast.*, p. 431.

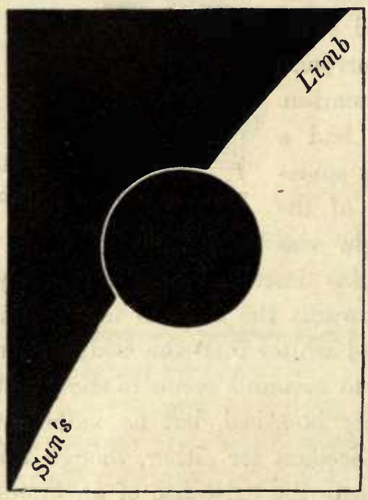
[z] *Append. Ad. Ephem. Astron.*, 1766, p. 62.

A ring of light was seen by many observers round Venus during the transit of Dec. 8, 1874, which the engraving above, dated 1769, would seemingly represent equally well [a].

Figs. 163 to 168 are 6 views of Venus at the transit of 1874, drawn by E. J. Stone, who used the 7-inch refractor of the Cape Observatory: their large scale renders them of great interest, but it does not seem necessary to transcribe his notes on each, which are however very brief [b].

It will be remembered that transits of Venus are of importance in two senses; firstly, as affording a means of ascertaining the Earth's distance from the Sun; and secondly, for what they disclose respecting the physical circumstances of the planet. In this place we are dealing only with the second subject, the first having been handled in Book I. Chapter I. (*ante*).

Fig. 162.



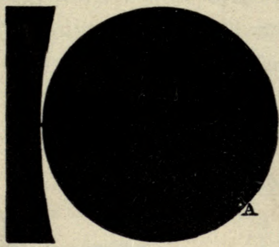
VENUS JUST BEFORE THE COMMENCEMENT OF ITS TRANSIT, 1882. (*Prince.*)

In anticipation of the transit of 1882 very extensive preparations were made by all the leading European Governments, and the American Government [c]. And many amateurs joined in the work. In England a part only of the transit was visible, and bad weather generally prevailed which interfered with such part as otherwise might have been seen. Shortly before the planet entered on the Sun's disc that portion of its limb which was outside the Sun appeared, according to Prince, "to be illuminated by a brilliant silver line

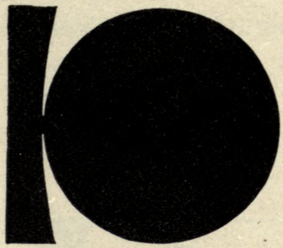
[a] *Month. Not.*, vol. xxxv. p. 133 (Jan. 1875); p. 310 (March 1875). For a full account of the observations of 1874 see *Mem.* R.A.S., vol. xlvii. p. 31, 1883.

[b] *Mem.* R.A.S., vol. xlvii. p. 101. 1883.

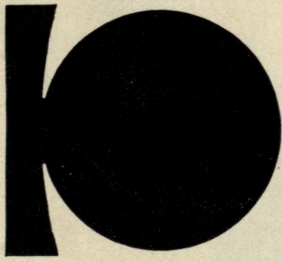
[c] The American Government issued a very important and exhaustive series of *Instructions.* (4to. Washington, U.S. 1882.)



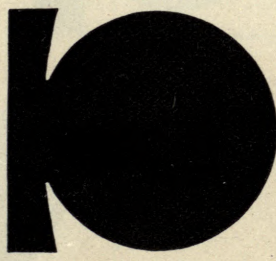
h. m. s.
At 19 7 12
FIRST FORMATION OF LIGAMENT.



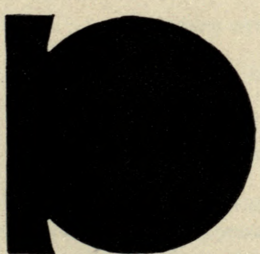
h. m. s.
At 19 7 29
APPARENT CONTACT NOT PERFECT.



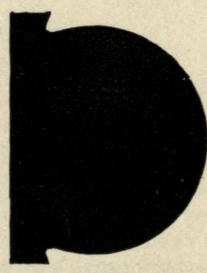
h. m. s.
At 19 8 5
APPARENT CONTACT.



h. m. s.
At 19 9 29
THE LIGAMENT BROAD.



h. m. s.
At 19 14 20
THE LIGAMENT BROADER.



h. m. s.
At 19 19 20
THE LIGAMENT BROADEST.

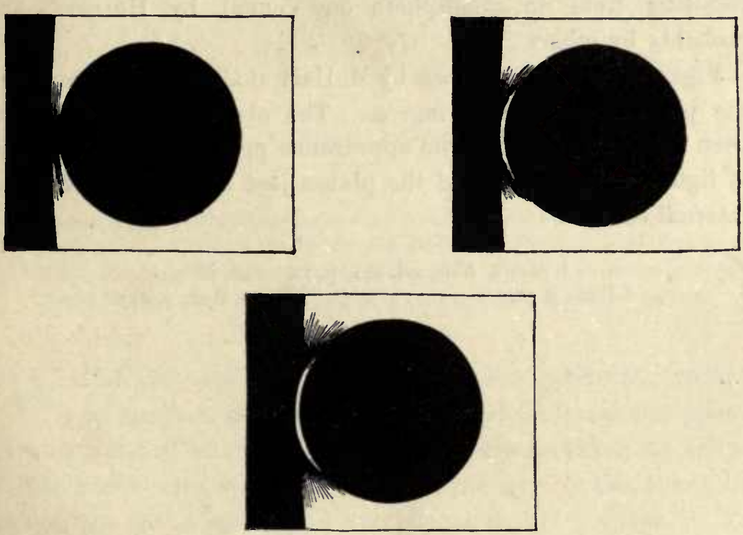
VENUS DURING ITS TRANSIT IN 1874.

(*Drawn by E. J. Stone.*)

of light, which most distinctly marked the limb of that portion of the planet, and which was doubtless produced by the refraction of sunlight passing through the planet's atmosphere. The effect was very beautiful[d]."

This illuminated streak, but far less sharply defined than

Figs. 169—171.



h. m. s.	h. m. s.	h. m. s.
At 14 55 30	14 55 56	14 56 11
Loc. Sid. Time.	Loc. Sid. Time.	Loc. Sid. Time.

VENUS DURING ITS TRANSIT, 1882.

Prince saw it, was also observed in America by Prof. S. P. Langley, who says :—

"It was therefore watched by me, with occasional interruptions, for about 7^{m}. Owing to the boiling of the limb, it was not easy to determine how much of this light lay without, how much within, the planet's contour. When first seen, it suggested for a moment the appearance of Baily's Beads, but the writer's very strong final impression was that it at any rate extended to some degree within the planet, and was brightest on the outside, with a slight gradation toward the planet's centre. Its greatest width was estimated at one-fourth of the planet's radius. Every precaution was taken against instrumental error. The spot was successively examined in different parts of the field, the eye-piece was rotated, and the amount of light

[d] *Month. Not.*, vol. xliii. p. 64. Dec. 1882.

from the reflectors was varied. It was beyond any question a real, if a most unexpected and unintelligible phenomenon, and it seems to me that it points to a real local cause on the planet. It does not appear to be at all assimilable to the concentric spots which some observers have believed they saw both on Venus and on Mercury in transit, nor to the alleged phosphorescence on the dark side [e]."

This phenomenon, with variations of detail, was seen by Brodie [f] (by whom it was assumed to be a twilight effect resulting from an atmosphere on Venus), by Horner [g], and probably by others.

Figs. 169–171 were drawn by M. Hatt at Chubut, and represent the phenomena seen at ingress. The observer seems to have been much struck with the appearance presented by the fringe of light which surrounded the planet just before the end of the internal contact.

[e] *Month. Not.*, vol. xliii. p. 72. Jan. 1883.
[f] Ibid., p. 76.
[g] Ibid., p. 277.

CHAPTER XI.

OCCULTATIONS.

How caused.—Table annually given in the "Nautical Almanac."—Occultation by a young Moon.—Effect of the Horizontal Parallax.—Projection of Stars on the Moon's disc.—Occultation of Jupiter, January 2, 1857.*—Occultation of Saturn, May* 8, 1859.*—Occultation of Saturn, April* 9, 1883.*—Historical notices.*

WHEN any celestial object is concealed by the interposition of another, it is said to be "occulted," and the phenomenon is called an "occultation." Strictly speaking, an eclipse of the Sun is an occultation of that luminary by the Moon, but usage has given to it the special name of "eclipse." The most important phenomena of this kind are the occultations of the planets and larger stars by the Moon, but the occultation of one planet by another, on account of the rarity of such an occurrence, is exceedingly interesting. Inasmuch as the Moon's apparent diameter is about $\frac{1}{2}°$, it follows that all stars and planets situated in a zone extending $\frac{1}{4}°$ on each side of her path will necessarily be occulted during her monthly course through the ecliptic, and parallax will have the effect of further increasing considerably the breadth of the zone of stars subject to occultation. The great brilliancy of the Moon entirely overpowers the smaller stars, but the disappearances of the more conspicuous ones can be observed with a telescope, and a table of them is inserted every year in the *Nautical Almanac.*

It must be remembered that the disappearance always takes place at the limb of the Moon which is presented in the direction of its motion. From the epoch of its New to that of its Full phase the Moon moves with the dark edge foremost, and from the epoch of its Full to that of its New phase with the illuminated edge foremost: during the former interval, therefore, the objects occulted disappear at the dark edge, and reappear at the illuminated edge; and during the latter period they disappear at the illuminated, and reappear at the dark edge. If the occultation be watched when the star disappears on the dark side of the Moon, that is to say during the first half of a lunation, and preferably when the Moon is not more than 2 or 3 days old, the disappearance is extremely striking, inasmuch as the object occulted is suddenly extinguished at a point of the sky where there seems nothing to interfere with it. Wargentin relates that on May 18, 1761, he saw an occultation of a star by the Moon during a total eclipse of the latter. He says that the star disappeared "more quickly than the twinkling of an eye[a]." In consequence of the effect of parallax, the Moon, as seen in the Northern hemisphere, follows a path different from that which it appears to take as seen in the Southern hemisphere; it happens, therefore, that stars which are occulted in certain latitudes are not occulted at all in others, and of those which are occulted the duration of invisibility, and the moment and place of disappearance and reappearance, are different.

I must not omit a passing allusion to a circumstance occasionally noticed by the observers of occultations; namely, the apparent projection of the star *within* the margin of the Moon's disc.

Admiral Smyth gives an instance, under the date of October 15, 1829. He says:—

"I saw Aldebaran approach the bright limb of the Moon very steadily; but, from the haze, no alteration in the redness of its colour was perceptible. It kept the same steady line *to about $\frac{3}{4}$ of a minute inside the lunar disc*, where it remained, as precisely as I could estimate, $2\frac{1}{4}$ seconds, when it suddenly vanished. In this there could be no mistake, because I clearly saw the bright line of the Moon *outside* the star, as did also Dr. Lee, who was with me[b]."

[a] *Phil. Trans.*, vol. li. p. 210. 1761.

[b] *Mem.* R.A.S., vol. iv. p. 642. 1831. Other observers, Maclear included, saw the projection, though F. Baily and others did *not* see it.

Sir T. Maclear saw the same thing happen to the same star on October 23, 1831 :—

"Previous to the contact of the Moon and star nothing particular occurred; but at that moment, and when I might expect the star to immerge, it advanced upon the Moon's limb for about 3 seconds, and to rather more than the star's apparent diameter, and then instantly disappeared [c]."

"This phenomenon seems to be owing to the greater proportionate refrangibility of the white lunar light, than that of the red light of the star, elevating her apparent disc at the time and point of contact [d]."

In 1699 La Hire endeavoured to explain the apparition of stars on the Moon's disc by supposing that the true disc is accompanied by a parasitic light, or, as it was formerly termed, a circle of dissipation, which enlarges the star's apparent diameter, and through which it shews itself before passing behind the opaque part of the lunar globe. Arago accepted this theory with the explanation that the observer's eye-piece must be in imperfect focus, and that so the false disc is caused. The fact that some have and some have not seen the phenomenon he considered confirmatory of this explanation [e].

The present state of the question is that we do not possess any certain explanation of the phenomenon.

A remarkable occurrence was noticed by Mr. Ralph Copeland, on the occasion of the occultation of κ Cancri on April 26, 1863 :—

"About three-fourths of the light disappeared in the usual instantaneous manner; and after an interval of (as near as I can judge) rather more than half a second, the remaining portion disappeared."

Dawes regarded this as a decisive indication that the star was double, though he failed to verify this surmise [f]. On Oct. 30,

[c] *Mem.* R.A.S., vol. v. p. 373. 1833.

[d] Smyth.

[e] *Pop. Ast.*, vol. ii. p. 348, Eng. ed. For other remarks on this phenomenon, see papers by Airy in *Mem.* R.A.S., vol. xxviii. p. 173, 1860, and *Month. Not.*, vol. xix. p. 208 (April 1859), and one by Stevelly discussing the Diffraction hypothesis in *Brit. Assoc. Rep.*, 1845; Transactions of the Sections, p. 5. Also one by Plummer in *Month. Not.*, vol. xxxiii. p. 345 (March 1873).

[f] *Month. Not.*, vol. xxiii. p. 221 (May 1863).

1863, I watched the emersion of ψ^1 Orionis, and it was unquestionably not instantaneous.

An occultation of the planet Jupiter took place on January 2, 1857. A dark shadowy streak which appeared projected on the planet, from the edge of the Moon, was seen by several observers.

Fig. 172.

OCCULTATION OF JUPITER BY THE MOON: January 2, 1857. (*Lassell.*)

Mr. W. Simms, Sen. thus described it:—

"The only remarkable appearance noticed by me during the emersion was the very positive line by which the Moon's limb was marked upon the planet; dark as the mark of a black-lead pencil close to the limb, and gradually softened off as the distance increased[g]."

A representation of this appearance, from a drawing by Lassell, is annexed [Fig. 172].

An occultation of the planet Saturn by the Moon took place on May 8, 1859. Dawes thus described it:—

"At the disappearance, the dark edge of the Moon was sharply defined on the rings and ball of the planet, without the slightest distortion of their figure. There was no extension of light along the Moon's limb. Even the satellites disappeared without the slightest warning, and precisely at the edge which was faintly visible.

"At the reappearance I could not perceive any dark shading contiguous to the Moon's bright edge, such as was seen by myself and several other observers on Jupiter on January 2, 1858 [Qy. 1857]. The dark belt south of the planet's equator was clearly defined up to the very edge; and there was no distortion of any kind, either of the rings or ball.

"The very pale greenish hue of Saturn contrasted strikingly with the brilliant yellowish light of the Moon[h]."

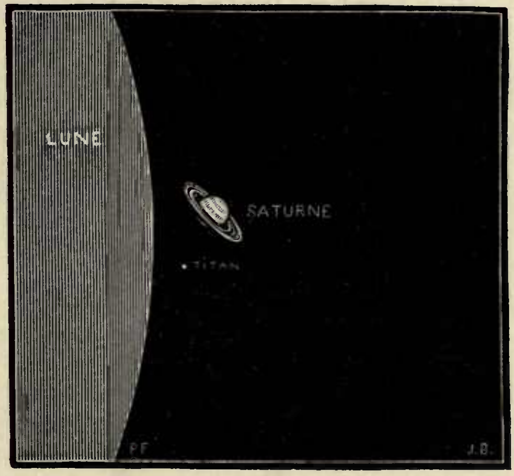
[g] *Month. Not.*, vol. xvii. p. 81 (Jan. 1857).

[h] *Month. Not.*, vol. xix. p. 241 (May 1859). Other observations will be found at p. 238 of the same volume.

Mr. W. Simms, Jun. *did* see a dark shading on the planet contiguous to the Moon's bright edge; but in 1857 he failed to notice it.

The occultation of Saturn on April 9, 1883, was observed by Mr. L. W. Loomis, who remarked on the impression being vividly conveyed that the Moon was very much nearer to the eye than Saturn. The successive disappearance of the rings was an extremely interesting phenomenon.

Fig. 173.



OCCULTATION OF SATURN BY THE MOON: April 9, 1883. (*L. W. Loomis.*)

In an occultation of Saturn on Oct. 30, 1825, Messrs. R. Comfield and J. Wallis plainly saw both one ansa and the ball *flattened*[i].

The earliest record which we have of an occultation is that of an occultation of Mars by the Moon, mentioned by Aristotle[k]. Kepler found that it occurred on the night of April 4, 357 B.C.[l]

Instances are on record of one planet occulting another, but these are of very rare occurrence. Kepler states that he watched an occultation of Jupiter by Mars on January 9, 1591. He also

[i] *Mem.* R.A.S., vol. ii. p. 457. 1826.
[k] *De Cœlo*, lib. ii. cap 12.
[l] *Ad Vitell. Paralipom.*, p. 307.

mentions that Mœstlin witnessed an occultation of Mars by Venus on October 3, 1590. Mercury was occulted by Venus on May 17, 1737[m]. As these observations, with the exception of the last, were made before the invention of the telescope, it is possible that the one planet was not actually in front of the other, but only that they were so close together as to have had the appearance of being one object: as was the case with Venus and Jupiter on July 21, 1859.

Sometimes stars are occulted by planets. J. D. Cassini mentions the occultation of a star in Aquarius by Mars on October 1, 1672[n].

[m] *Phil. Trans.*, vol. xl. p. 394. 1738.

[n] See a paper on Occultations by A. C. Twining in *Amer. Journ. of Science*, 2nd Ser., vol. xxvi. p. 15. July, 1858.

BOOK III.

PHYSICAL AND MISCELLANEOUS ASTRONOMICAL PHENOMENA.

CHAPTER I.

THE TIDES.

"O ye seas and floods, bless ye the LORD: praise Him, and magnify Him for ever."—*Benedicite.*

Introduction.—Physical cause of the Tides.—Attractive force exercised by the Moon.—By the Sun.—Spring Tides.—Neap Tides.—Summary of the principal facts.—Priming and Lagging.—Diurnal Inequality.

MANY inhabitants of a maritime country like Great Britain have some acquaintance with the phenomena now to come under consideration, but beyond a vague notion that the Moon has something to do with the tides, very few people have an intelligent idea of the way in which the tides are produced[a].

These phenomena are very frequently attributed to the attraction of the Moon, whereby the waters of the ocean are drawn towards that side of the Earth on which our satellite happens to be situated; in fact, that it is high water when the Moon is on or near the meridian of the place of observation.

This, though to a great extent true, by no means adequately

[a] See a paper by the late Sir J. Lubbock, in the *Companion to the Almanac* for 1830, p. 49. And reference should also be made to an important and exhaustive Memoir on "Tides and Waves" by Sir G. B. Airy, in *Encycl. Metrop.*, vol. v. p. 241. There are maps of co-tidal lines around the British Isles, and over the World generally, which will be found of interest.

represents the facts of the case, for high water is not only produced on the side of the Earth immediately under the Moon, but also on the opposite side at the same time. The coincident tides are therefore separated from each other by 180°, or by half the circumference of the globe. Since the diurnal rotation of the Earth causes every portion of its surface to pass successively under the tidal waves in about 24^h, it follows that there are everywhere 2 tides daily, with an interval of about 12^h between each; whereas, if the common supposition were correct, there would be only one.

Such being the observed facts, and it being admitted that the attraction of the Moon gives rise to the upper tide, some further explanation must be sought to account for the lower one. The solution is extremely simple as an elementary conception: it is only necessary to bear in mind that not only does the Moon attract the upper mass of water, but also the solid globe itself, which is consequently compelled to recede from the waters beneath, leaving them behind, and in a sense heaped together.

Besides the influence of the Moon in elevating the waters of the ocean, that of the Sun is to some extent concerned, but it is much more feeble than that of the former, on account of the much greater distance of the solar globe. The mean distance of the Sun from the Earth is 309·144 times that of the Moon; its attractive power is consequently $(309·144)^2$, or 95,570 times less; but inasmuch as the mass of the Sun exceeds that of the Moon in the ratio of 25,916,280 to 1, which is much greater than 95,570 to 1, it will naturally be said that surely the attraction exercised by the Sun exceeds that of the Moon in the same proportion that 25,916,280 exceeds 95,570[b]. This, however, is not the case, for a reason which will now be stated. It must be borne in mind that the tides are due solely to the *inequality* of the attraction in operation on different sides of the Earth, and that the greater that inequality is the greater will be the resulting tide, and *vice versâ*. The mean distance of the Sun from

[b] To avoid complicating the obviously crude argument in the text certain things are left out of consideration.

the Earth is 11,720 diameters of the latter, and consequently the difference between its distance from the one side of the Earth and from the other will be only $\frac{1}{11720}$ of the whole distance, while in the case of the Moon, whose mean distance is only 30 terrestrial diameters, the difference between the distances from one side and from the other, reckoned from the Moon, will be $\frac{1}{30}$ of the whole distance. The inequality of the attraction (upon which the height of the tidal wave depends) is therefore much greater in the case of the Moon than of the Sun; the ratio, according to Newton, being 58 : 23, or about $2\frac{1}{2}$: 1.

We thus see that there are 2 kinds of tides, lunar and solar. When therefore the Sun, Moon, and Earth are in the same straight line with each other, that is to say, when it is either *New* or *Full Moon*, the attractions of the two former bodies act in the same line, and we have the highest possible tidal elevations, and what are known as "*Spring tides*;" but when the Moon is in quadrature, or 90° from the Sun, its attraction acts along a line which is perpendicular to that along which the attraction of the Sun acts, the two tidal elevations are 90° apart, and we have the tides which are called "*Neap.*"

It may be convenient to state here a few general facts relating to the tides:—

1. On the day of New Moon, the Sun and Moon cross the meridian at the same time, *i. e.* at noon, and at an interval after their passage (varying according to the place of observation, but unchangeable or nearly so for each place) high water occurs. The water, having reached its maximum height, begins to fall, and after a period of $6^h\ 12^m$ attains a maximum depression; it then rises for $6^h\ 12^m$, and reaches a second maximum; falls for another interval of $6^h\ 12^m$, and rises again during a 4th interval of $6^h\ 12^m$.[c] It has therefore 2 maxima and 2 minima in a period of $24^h\ 48^m$, which is called a *Tidal Day*.

2. On the day of Full Moon, the Moon crosses the meridian

[c] Practically this is somewhat incorrectly expressed, for it is found that the intermediate low water does not take place at the mean moment between the two tides, the waters usually taking a shorter time to rise than they do to fall.

12^h after the Sun, *i.e.* at midnight, and the tidal phenomena are the same as in (1).

3. As time is reckoned by the apparent motion of the Sun, the solar tide always happens at the same hour at the same place, but the lunar tide, which is the greater, and thereby gives a character to the whole, happens 48^m 44^s later every day; it therefore separates Eastwards from the solar tide, at that rate, and gradually becomes later and later, till at the periods of the 1^{st} and 3^{rd} quarters of the Moon it happens at the same time as the low water of the solar tide: then the elevation of the high, and the depression of the low water, will be the difference of the solar and the lunar tides, and the tide will be neap.

4. The difference in height between the high and low water is called the *Range of the tide.*

5. The spring tides are highest, especially those which happen 36^h after the New, or Full Moon.

6. The neap tides are the lowest, especially those which happen 36^h after the Moon is in quadrature.

7. The interval of time from Noon to the time of high water at any particular place is the same on the days both of New and Full Moon. This interval is technically known as the "*Establishment of the port.*"

The reason why an interval of time elapses between the Moon's meridian passage and the time of high water is, that the waters of the ocean have to overcome a certain peculiar effect of friction, which cannot immediately be accomplished; it thus happens that the lunar tidal wave is not found immediately under the Moon, but follows it at some distance. Similar results ensue in the case of the solar wave. The tidal wave is also affected in another way, by the continued action of both these luminaries, and at certain periods of the lunar month is either accelerated or retarded in a way which will now be described: "In the 1^{st} and 3^{rd} quarters of the Moon, the solar tide is Westward of the lunar one; and consequently the actual high water (which is the result of the combination of the 2 waves) will be to the Westward of the place it would have been at if the Moon had acted alone, and the time of high water will therefore be accelerated. In the 2^{nd} and 4^{th} quarters, the general effect of the Sun is, for a similar reason, to produce a retardation in the time of high water. This effect, produced by the Sun and Moon combined, is called the *Priming* and *Lagging* of the tides. The highest spring tides occur when the Moon passes the meridian about $1\frac{1}{2}^{h}$ after the Sun; for then the maximum effect of the 2 bodies coincides." The "priming" and "lagging" effect deranges the average retardation, which from a mean value of 48^{m} may be augmented to 60^{m} or be reduced to 36^{m}.

The 2 tides following one another are also subject to a variation, called the *Diurnal Inequality*, depending on the daily change in declination of the Sun and Moon; the laws which govern it are, however, very imperfectly known.

Guillemin writes:—"The height of the tides again varies with the declinations of the Moon and Sun; it is by so much greater as the two bodies are nearer the equator. Twice a year, towards March 21 and Sept. 22, the Sun is actually in the equator. If, at the same time, the Moon is near the same plane the tides which occur then are the highest of all. These are the *Equinoctial Spring Tides*, because the Earth is then at the vernal or autumnal equinox. On the other hand, the smallest tides take place towards the solstices, if the Moon attains its smallest or its greatest meridional height at the same time as the Sun. Lastly, the distances of the Moon and Sun from the Earth have also their influence on the height of the tides. Other things being equal, the height of a tide is greater or less, according as the attracting bodies are nearer to or farther from the Earth. Thus the tides of the winter solstice are higher than those of the summer one[d]."

[d] *The Heavens.* Eng. ed., p. 461.

CHAPTER II.

LOCAL TIDAL PHENOMENA.

Local disturbing influences.—Table of Tidal ranges.—Influence of the Wind.—Experiment of Smeaton.—The Tides in the Severn at Chepstow.—Tidal phenomena in the Pacific Ocean.—Remarks by Beechey.—Velocity of the great Terrestrial Tidal wave.—Its course round the Earth, sketched by Johnston.—Effects of Tides at Bristol.—Instinct of animals.—Tides extinguished in rivers.—Instances of abnormal Tidal Phenomena.—The "Mascaret" on the Seine.—Historical notices.

WE have hitherto been considering the tidal wave, on the supposition of the Earth being a perfect sphere covered with water to a uniform depth; but inasmuch as this is not the case, it follows that the actual phenomena of the tides are widely different and of a much more complicated character, owing to the irregular outline of the land, the uneven surface of the ocean bed, the action of winds, currents, friction, &c. The effects of these disturbing influences are rendered especially manifest in the difference of the range of the tide at different places on the Earth's surface. If the surface of our globe were entirely covered with water, the height of a solar tide would be $1^{ft}\ 11\frac{1}{30}{}^{in}$, and of a lunar tide $4^{ft}\ 0^{in}$; but the differences in the level of the water of the ocean brought about by tidal influences are often far in excess of these figures. For instance, in deep estuaries or creeks, open in the direction of the tidal wave, and gradually converging inward, the range is very much greater than elsewhere, as at:—

	Feet.
Bay of Fundy [a]	50
Gallegos River (Patagonia)	46
Mouth of the Avon	42
St. Malo	40
Bristol Channel (off Chepstow [a])	38
Milford Haven	36

On the other hand, where promontories or headlands jut out into the sea, the tidal range is frequently small; thus:—

	Feet.
Wicklow	4
Weymouth	7
The Needles	9
Cape Clear	11

In very large open waters, like the Atlantic or the Pacific Oceans, and in confined seas, like the Baltic, the Mediterranean, &c., the elevation of the tidal wave is inconsiderable; thus:—

	Feet.	Inches.
Toulon	1	0
Antium	1	2
Porto Rico (S. Juan)	1	6
South Pacific	1	8
St. Helena	3	0

The usual range of the tides at any particular place is also affected by certain conditions of the atmosphere. At Brest, a depression of 1^{in} in the barometric column causes a difference of 16^{in} in the elevation of the high-water mark; at Liverpool, corresponding to the depression of 1^{in}, the difference is about 10^{in}; and at the London Docks about 7^{in}: thus when the barometer is low, an unusually high tide may be expected, and *vice versâ*. And the influence of the wind also is frequently very considerable, so much so that during a violent hurricane, Jan. 8, 1839, there was no tide at all at Gainsborough on the river Trent, a circumstance never before recorded. Smeaton found experimentally in a canal 4 miles long, that the water-level at one end was 4^{in} higher than at the other, owing to the force of the wind acting on the surface of the water.

[a] See *Nature*, vol. xix. p. 432. March 13, 1879.

Concerning the tides at Chepstow, Mr. A. Miller, the lessee of the Fisheries there, wrote to me thus, under date of June 7, 1888:—

"The rise and fall of the spring tides at Chepstow, New Passage on Severn, and Clevedon piers, is 45 to 46^{ft}, taken as the highest spring tide. There is scarcely 6^{in} difference at either of these points. I have had careful measurements taken for several years. Four years ago [October 17, 1883], the tide rose to 48^{ft} or 49^{ft}. This was caused by a gale of wind and a very exceptional high flood from the hills, the result of unusually heavy rain. The houses in the lower part of the town were flooded 2^{ft} deep, and the river overflowed its banks in the Bristol Channel. The same thing occurred in 1854. These measurements were taken from low-water mark to high-water mark, not from the bed of the river or channel. The tidal wave or bore on the Severn begins at the Lyde rock just below Beachley and immediately above the mouth of the Wye. I have known it go up the Wye for about 4 miles in the shape of an unbroken wave 18^{in} high."

The tides in the Pacific Ocean present great anomalies. The following remarks respecting them are by a missionary:—

"It is, to the missionaries, a well-known fact that the tides in Tahiti and the Society Islands are uniform throughout the year, both as to the time of the ebb and flow, and the height of the rise and fall, it being high water invariably at noon and at midnight, and consequently the water is at its lowest point at 6 o'clock in the morning and evening. The rise is seldom more than 18 inches or 2 feet above low-water mark. It must be observed that mostly once, and frequently twice in the year, a very heavy sea rolls over the reef, and bursts with great violence upon the shore. But the most remarkable feature in the periodically high sea is, that it invariably comes from the W. or S.W., which is the opposite direction to that from which the Trade wind blows. The eastern sides of the island are, I believe, never injured by these periodical inundations. I have been thus particular in my observations, for the purpose in the first place of calling the attention of scientific men to this remarkable phenomenon, as I believe it is restricted to the Tahitian and Society Island Groups in the South Pacific, and the Sandwich Islands in the North. I cannot, however, speak positively respecting the tides at the islands eastward of Tahiti; but all the islands I have visited in the same parallel of longitude southwards, and in those to the westward in the same parallel of latitude, the same regularity is *not* observed, but the tides vary with the Moon, both as to the time and the height of the rise and fall, which is the case at Raratonga [b]."

[b] J. Williams, *Narrative of Missionary Enterprises in the South Seas*, p. 201.

The late Admiral Beechey is, so far as I know, the only person who ever attempted any solution of the question, and he proposed as a simile, a basin to represent the harbour, over the margin of which the sea breaks with considerable violence, thereby throwing in a larger body of water than the narrow channels can carry off in the same time, and consequently the tide rises, and as the wind abates the water subsides.

The writer above quoted objects to this explanation, and he brings forward several arguments, and states several facts, of which the following is an abstract:—

1. The undeviating regularity of the tide is so well understood by the natives that they distinguish the hours of the day by terms descriptive of the state of the tide, such as the following: "Where is the tide?" instead of, as we should say, "What o'clock is it?"

2. There are many days during the year when it is perfectly calm, and yet the tide rises and falls in the same way, and very frequently there are higher tides in calms than during the prevalence of the Trade wind.

3. The tides are as regular on the West side of the island, where the Trade wind does not reach, as on the East, from which point it blows.

4. The Trade wind is most powerful from noon till 4 or 5 o'clock P.M., during which time the water ebbs so fast that it reaches its lowest level by 6 o'clock P.M., instead of in the morning, as Admiral Beechey states, at which time it is again high water.

Admiral Beechey's explanation does not seem very satisfactory, but we are not in possession of any other.

The velocity of the tidal wave is subject to much variation, and we are not yet in a position to lay down the laws which govern it. If the whole globe were uniformly covered, the velocity would be rather more than 1000 miles per hour ($7926 \times 3{\cdot}1416 \div 24{\cdot}8$). It is probably, however, nowhere equal to this, unless perhaps in the Antarctic Ocean.

The following table of velocities is given by Whewell [c]:—

	Miles.
In latitude 60° S.	670
In the Atlantic	700
Azores to Cape Clear	500
Cape Clear to Duncansby Head	160
Buchan Ness to Sunderland	60
Scarborough to Cromer	35
North Foreland to London	30
London to Richmond	13

Concerning the general character of the great terrestrial tidal wave, I cannot do better than quote the following description by a well-known eminent geographer:—

"The Antarctic is the cradle of tides. It is here that the Sun and Moon have presided over their birth, and it is here, also, that they are, so to speak, to attend on the guidance of their own congenital tendencies. The luminaries continue to travel round the Earth (apparently) from East to West. The tides no longer follow them. The Atlantic, for example, opens to them a long, deep canal, running from North to South, and after the great tidal elevation has entered the mouth of this Atlantic canal, it moves continually Northward; for the second 12 hours of its life it travels north from the Cape of Good Hope and Cape Horn, and at the end of the first 24 hours of its existence, has brought high water to Cape Blanco on the West of Africa, and Newfoundland on the American continent. Turning now round to the Eastward, and at right angles to its original direction, this great tidal wave brings high water, during the morning of the 2nd day, to the Western coasts of Ireland and England. Passing round the Northern cape of Scotland, it reaches Aberdeen at noon, bringing high water also to the opposite coasts of Norway and Denmark. It has now been travelling precisely in the opposite direction to that of its genesis, and in the opposite direction, also, to the relative motion of the Sun and Moon. But its erratic course is not yet complete. It is now travelling from the Northern mouth of the German Ocean Southwards. At midnight of the 2nd day it is at the mouth of the Thames, and wafts the merchandise of the world to the quays of the port of London. In the course of this rapid journey the reader will have noticed how the lines [on the map] in some parts are crowded together closely on each other, while in others they are wide asunder. This indicates that the tide-wave is travelling with varying velocity. Across the Southern Ocean it seems to travel nearly 1000 miles an hour, and through the Atlantic scarcely less; but near some of the shores, as on the coast of India, as on the East of Cape Horn, as round the shores of Great Britain, it travels very slowly; so that it takes more time to go from Aberdeen to London than over the arc of 120° which reaches from 60° of Southern latitude to 60° North of the Equator. These differences have still to be accounted for; and the high velocities are invariably found to exist where the water is deep, while the low velocities occur in shallow water. We must therefore look to the conformation of the shores and bottom of the sea as an important element in the phenomena of the tides [d]."

[c] *Phil. Trans.*, vol. cxxiii. p. 212. 1833.
[d] Johnston, *Phys. Atlas.*

Tidal effects on rivers are often very striking. Especially is this the case with the Avon at Bristol: when the tide is at its ebb, the river is little better than a shallow ditch, but when the waters have risen to the maximum height, an insignificant stream is converted into a broad and deep channel, navigable by the largest Indiaman.

The instinct of animals in respect of the tides is often very remarkable. A Scotch writer observes: "The accuracy with which cattle calculate the times of ebb and flow, and follow the diurnal variations, is such, that they are seldom mistaken, even when they have many miles to walk to the beach. In the same way they always secure their retreat from these insulated spots in such a manner that they are never surprised and drowned."

In their passage up rivers, tides are gradually extinguished, as will be seen from the following table relating to the Thames[e]:—

	Height.		Distance from Mouth.
London (Docks)	18 ft.	10 in.	60 m.
Putney	10	2	67½
Kew	7	1	73
Richmond	3	10	76
Teddington	1	4½	79

At certain places on the coast of Hampshire and Dorsetshire the waters of the ocean ebb and flow *twice* in 12 hours instead of only once, as is usual elsewhere. Southampton, Christchurch, Poole, Weymouth, and the Firth of Forth, may be mentioned as places where this singular phenomenon has been observed[f].

Macculloch, the Scotch writer just quoted, says that in the strait between the island of Isla and the islets of Chenzie and Oersa the time of the ebb is 10¾ hours, and that of the flood only 1¼ hour[g].

Another abnormal tidal phenomenon, presenting some remarkable features, occurs once a year in the rivers Severn, Humber[h], and Loire, and in some other rivers[i] of the same

[e] *Phil. Trans.*, vol. cxxiii. p. 204. 1833.

[f] *Phil. Trans.*, vol. cxxiii. p. 226. 1833.

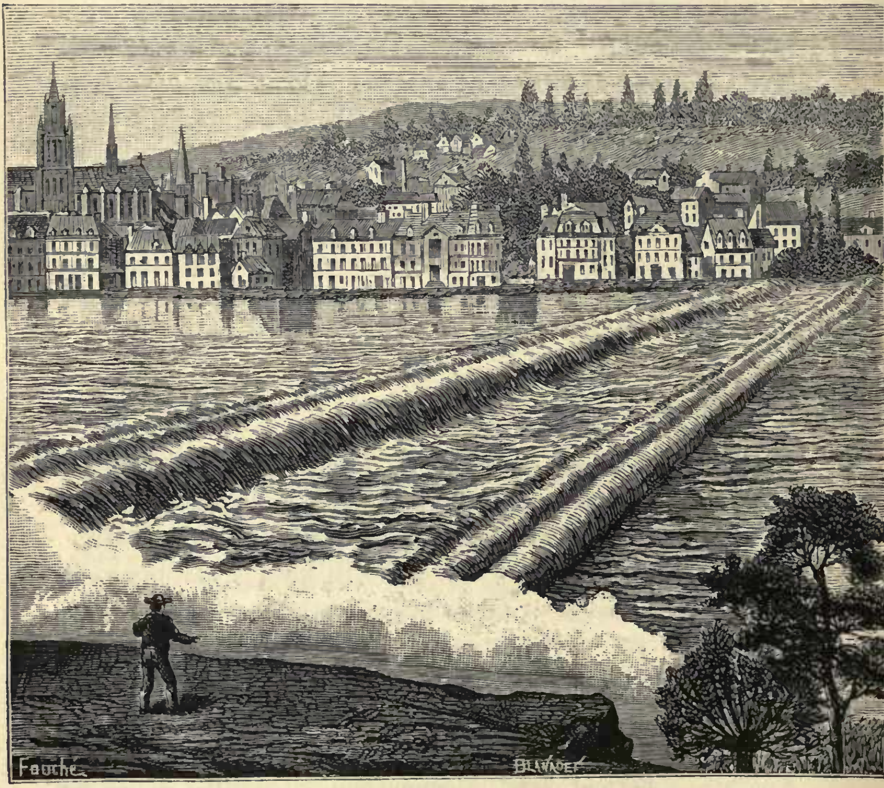
[g] J. Macculloch, *Description of the Western Islands of Scotland*, 1824, vol. ii. p. 225.

[h] White, *Eastern England*, vol. ii. ch. 3.

[i] The river Dordogne in France is occasionally the scene of a natural phenomenon which would appear to present some analogy to the "Bore" of the Severn. And I believe that the Dee at Chester furnishes another instance.

character as regards the formation of their banks. This is the "hygre," or "bore," and is due to the fact that a wide estuary at the mouth of the river suddenly contracts like a funnel. The result is, that the estual spring tide rushes up with an over-powering force, carrying all befoie it. This further peculiarity

Fig. 174.



THE "MASCARET" ON THE SEINE, FRANCE.

likewise subsists: namely, that there is no "slack-water," as is ordinarily the case in other rivers, between the ebb and flow of the tide. The approach of the bore on the Severn may be heard at a considerable distance roaring, as it were, in its upward progress. The head is about 3^{ft} high, and it frequently does a good deal of mischief to property. The maximum effect is at the 4th tide after the Full Moon.

Fig. 174, represents the tidal phenomenon known as the "Mascaret" on certain French rivers, especially the Garonne and the Seine, which corresponds with the "Bore" of the Severn.

An inspection of the engraving coupled with the remarks made above will sufficiently indicate the general character of the phenomenon[k].

The evident connexion between the periods of the tides and those of the phases of the Moon led to the tides being attributed to the Moon's action long before their true theory was understood. Aristotle[l] and Pytheas of Marseilles[m] are both said to have pointed out the connexion. Julius Cæsar adverts to the connexion existing between the Moon and spring tides[n].

Pliny says: "Æstus maris accedere et reciprocare, maxime mirum: pluribus quidem modis: *verum causa in sole lunâque*[o]." Kepler clearly indicated that the principle of gravitation is concerned[p]—an opinion from which Galileo strongly dissented[q]. Wallis, in 1666, also published a tidal theory[r]. Before Sir Isaac Newton turned his attention to this subject, the explanations given were at best but vague surmises. "To him was reserved the glory of discovering the true theory of these most remarkable phenomena, and of tracing, in all its details, the operation of the cause which produces them."

[k] For further particulars in florid detail, see a paper by Flammarion in *L'Astronomie*, vol. v. p. 281, Aug. 1885.

[l] Περὶ Κόσμου.

[m] Plutarch, *De Placitis*, lib. iii. cap. 17.

[n] *De Bello Gallico*, lib. iv. cap. 29.

[o] Pliny, *Hist. Nat.*, lib. ii. cap. 99.

[p] *Epist. Ast.*, p. 555.

[q] *Dialoghi.*

[r] *Phil. Trans.*, vol. i. p. 263. 1666.

CHAPTER III.

PHYSICAL PHENOMENA.

Secular Variation in the Obliquity of the Ecliptic.—Precession.—Its value.—Its physical cause.—Correction for Precession.—History of its discovery.—Nutation. —Herschel's definition of it.—Connexion between Precession and Nutation.

SECULAR Variation in the Obliquity of the Ecliptic.—Although it is sufficiently near for most purposes to consider the inclination of the plane of the ecliptic to that of the equator as invariable, yet this is not strictly the case, inasmuch as it is subject to a small but appreciable change of 46·45″ (C. A. F. Peters) per century. This phenomenon has long been known to astronomers, on account of the increase it causes in the latitude of all stars in some situations, accompanied by a corresponding decrease in the opposite regions. Its effect at the present time is to diminish the inclination of the planes of the equator and the ecliptic to each other; but this diminution will not go on[a] beyond certain very moderate limits, after which it will again increase, and thus oscillate backwards and forwards through an arc of 1° 21′, the time occupied in one oscillation being about 10,000 years. One effect of this variation of the plane of the ecliptic—that which causes its nodes on a fixed plane to change—is associated with the phenomena of the precession of the equinoxes, and cannot be distinguished from it, except in theory[b].

Precession.—The precession of the equinoxes is a slow but

[a] Compare *Genesis* viii. 22.

[b] The inclination of the ecliptic for the epoch of January 1, 1890, is 23° 27′ 12·79″.

continual shifting of the equinoctial points from East to West[c]. Celestial longitudes and right ascensions are reckoned from the vernal equinox, and if this were a fixed point, the longitude of a star would never vary, but would remain the same from age to age as does its latitude (*sensibly*). Such, however, is not the case; as it has been found that *apparently* all the stars have changed their places since the first observations were made by the astronomers of antiquity[d]. Two explanations only can be given to account for this phenomenon: we must either suppose that the whole firmament has advanced, or that the equinoctial points have receded. And as these points depend on the Earth's motion, it is far more reasonable to suppose that the phenomenon is owing to some perturbation of our globe rather than that the starry heavens should have a real motion relative to these points. The latter explanation is accordingly adopted, namely, that the equinoxes have a periodical retrograde motion from *East* to *West*, thereby causing the Sun to arrive at them sooner than it otherwise would had these points remained stationary. The annual amount of this motion is, however, exceedingly small, being only equal to 50·2″[e]; and since the circle of the ecliptic is divided into 360°, it follows that the time occupied by the equinoctial

[c] It may be well to mention that the equinoxes are the two points where the ecliptic cuts the equator; and are so called because when the Sun in its annual course arrives at either of them, day and night are equal throughout the world. The point where the Sun crosses the equator, going north, is known as the *vernal equinox;* and the opposite point, through which the Sun passes going south, as the *autumnal equinox.* These intersecting points are also termed nodes, and an imaginary line joining the two, *the line of nodes.* The ascending node (☊) answers to the vernal equinox, and the descending (☋) to the autumnal.

[d] By "change of place" is here meant change of position of the Sphere as a whole to certain fixed co-ordinates, not change of place of the stars *inter se*, so as to alter the figures of the Constellations; although many individual stars—as we shall see hereafter—have very considerable proper motions.

[e] Bessel, by a careful discussion of the most reliable observations, fixed the value of general precession for the epoch of 1750 at 50·21129″, and the value of luni-solar precession at 50·37572″. For the epoch of 1800 he gave for the value of the latter 50·36354″. The lunar precession is about 2½ times the solar precession, just as the lunar tide is 2½ times the solar tide, and for much the same reason, namely, the difference of the attractions. Dreyer's value for 1800 for the general precession is 50·2365″, and for the luni-solar precession 50·3752″ (*Copernicus*, vol. ii. p. 155. 1882). And see a paper by L. Struve, *Mém. de l'Acad. de St. Pétersbourg*, 7th Ser., vol. xxxv. p. 3, cited *Observatory*, vol. xi. p. 200, April 1888.

points in making a complete revolution of the heavens is 25,817 years. It is owing to precession that the Pole-star varies from age to age, and also that whilst the sidereal year, or *actual* revolution of the Earth round the Sun, is $365^d\ 6^h\ 9^m\ 11{\cdot}0^s$, the equinoctial, solar, or tropical year is only $365^d\ 5^h\ 48^m\ 46{\cdot}05^s$ (Airy). The successive returns of the Sun to the same equinoctial points must therefore precede its return to the same point on the ecliptic by $20^m\ 24{\cdot}95^s$ of time, which corresponds to about $50{\cdot}27''$ of arc. It is also on account of the precession of the equinoxes that the signs of the ecliptic do not now correspond with the constellations of the same name, but lie about 28° Westward of them. Thus, that division of the ecliptic known as the *sign* of Taurus lies in the *constellation* Aries, the sign of Aries having passed into Pisces. It should be remarked, however, that the signs and constellations coincided with one another about 100 B.C. In recent times, the attempts that have been made to establish the motion of the solar system through space have rendered an accurate knowledge of precession indispensable; and the elaborate labours of C. A. F. Peters and O. Struve have led to a slight modification in the value of the constants of precession adopted by Bessel[f]. Their new value for the general precession is, for 1800, $50{\cdot}2411'' + 0{\cdot}0002268''\,t$.

"The cause of precession is to be found in the combined action of the Sun and Moon[g] upon the protuberant mass of matter accumulated at the Earth's equator, the attraction of the planets being scarcely sensible[h]. The attracting force of the Sun and Moon upon this shell of matter is of a two-fold character; one parallel to the equator, and the other perpendicular to it. The tendency of the latter force is to diminish the angle which the plane of the equator makes with the ecliptic; and were it not for the rotatory motion of the Earth, the planes would soon coincide; but, by this motion, the planes remain nearly constant to each other. The effect produced by the action of the force in question

[f] *Tabulæ Regiomontanæ.*

[g] Called hence, *luni-solar* precession.

[h] When the value of the constant of precession, given at any time, includes the variation caused by the planets, it is called the constant of *general* precession.

is, however, that the plane of the equator is constantly, though slowly, shifting its place in the manner we have endeavoured to describe."

In the reduction of astronomical observations the correction to be applied for precession in right ascension is almost always additive; increasing in the regions round the poles of the heavens, but becoming very small near the poles of the ecliptic. It is in the space included between these poles in each hemisphere that the correction becomes subtractive; in the northern hemisphere, this small space comprehends the constellations lying near the XVIII[th] hour of R.A., that being the R.A. of the North ecliptic pole; and in the southern hemisphere, the constellations lying near the VI[th] hour, that being the R.A. of the South ecliptic pole. The remarks I have just made apply only to those stars whose declination North or South exceeds 67°. The annual precession in declination, however, depends on the star's right ascension only, both as to amount and direction. At VI and XVIII hours it is at zero; at XII hours it reaches the Northern maximum of 20″; and at XXIV it reaches a similar Southern maximum. From XVIII to XXIV hours, and from XXIV to VI hours, the precession is N., consequently additive to stars of North declination, but subtractive from those of South declination: but from VI to XVIII, the precession being S., it is additive to Southern, and subtractive from Northern stars[i].

The discovery of precession dates from about 125 B.C., when it was detected by Hipparchus, by means of a comparison of his own observations with those of Timocharis and Aristyllus, made about 178 years previously: its existence was afterwards confirmed by Ptolemy[k]. It was Copernicus, however, who first gave the true explanation of the phenomenon, and Newton who discovered its physical cause.

Nutation[l].—It must be borne in mind that the effect of precession varies according to the time of year, on account of the ever-varying distance of the Earth from the Sun. Twice a

[i] A useful table of precessions will be given in a later volume of this work.

[k] *Almagest*, lib. vii.

[l] *Nutatio*, nodding.

year, (at the equinoxes,) the influence of the Sun is at zero ; and twice a year also, (at the solstices,) it is at its maximum. On no two successive days is it of exactly the same value, and consequently the precession of the equinoctial points is uneven, and the obliquity of the ecliptic is subject to a half-yearly variation ; since the Sun's force which changes the obliquity is constantly varying, while the rotation of the Earth is continuous. This then gives rise to a small oscillating motion of the Earth's axis, termed the *solar nutation :* of a far more considerable amount, however, is the value of the nutation arising from the agency of the Moon ; so much so that it was detected by Bradley before even its existence had been inferred from theory [m].

The nature of nutation cannot be better explained than in nearly the words of Sir J. Herschel, who says :—"The nutation of the Earth's axis is a small and slow gyratory movement, by which, if subsisting alone, the pole would describe among the stars, in a period of 18½ years, a minute ellipse having its longer axis equal to 18·5″, and its shorter to 13·74″ (the longer being directed towards the pole of the ecliptic, and the shorter of course at right angles to it) ; the semi-axis major is, therefore, equal to 9·25″, which quantity is called the '*coefficient of nutation* [n].' The consequence of this real motion of the pole is an apparent advance and recess of all the stars in the heavens to the pole in the same period. Since, also, the place of the equinox on the ecliptic is determined by the place of the pole in the heavens, the same agency will cause a small alternating motion to and fro of the equinoctial points, by which, in the same periods, both the longitudes and the right ascensions of the stars will be alternately increased and diminished.

"Precession and nutation, although for convenience here considered separately, in reality exist together ; they are, in fact, constituent parts of the same general phenomenon : and since, while in virtue of this nutation, the pole is describing its little ellipse

[m] *Phil. Trans.*, vol. xlv. p. 1. 1748.

[n] Other values are : Busch's 9·2320″, Lundahl's 9·2361″, C. A. F. Peters's 9·2164″. A mean of these, namely 9·2231″, is the value finally adopted by Peters. (*Numerus constans Nutationis*, 4to. Petropoli, 1842 : see p. 5 of W. Struve's *Rapport* on Peters's Memoir.)

of 18·5″ in diameter, it is carried on by the greater and regularly progressive motion of precession over so much of its circle round the pole of the ecliptic as corresponds to 18½ years—that is to say, over an angle 18½ times 50·1″ round the centre (which, in a small circle of 23° 28′ in diameter, corresponds to 6′ 20″, as seen from the centre of the sphere); the path which it will pursue in virtue of the joint influence of the 2 motions will be neither an ellipse nor an exact circle, but a slightly undulating ring.

"These movements of precession and nutation are common to all the celestial bodies, both fixed and erratic; and this circumstance makes it impossible to attribute them to any other cause than the real motion of the Earth's axis, as we have described. Did they only affect the stars, they might, with equal plausibility, be considered as arising from a *real* rotation of the starry heavens as a solid shell around our axis, passing through the poles of the ecliptic in 25,868 years, and a real elliptic gyration of *that* axis in rather more than 18 years: but since they also affect the Sun, Moon, and planets, which, having motions independent of the general body of the stars, cannot without extravagance be supposed to be *attached to* the celestial conclave, this idea falls to the ground; and there only remains, then, a real motion of the Earth by which they can be accounted for[o]."

[o] *Treatise on Ast.*, p. 172. 1833. In his *Outlines of Astronomy* Sir John altered this statement of nutation, but the original version strikes me as being the better of the two, and therefore I retain it here.

CHAPTER IV.

ABERRATION AND PARALLAX.

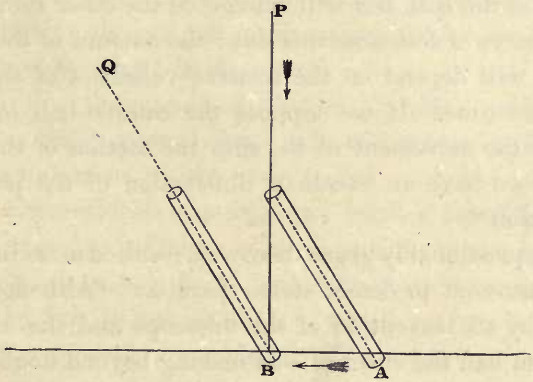
Aberration.—The constant of Aberration.—Familiar illustration.—History of the circumstances which led to its discovery by Bradley.—Parallax.—Explanation of its nature.—Parallax of the heavenly bodies.—Parallax of the Moon.—Importance of a correct determination of the Parallax of an object.—Leonard Digges on the distance of the Planets from the Earth.

ABERRATION.—The aberration of light is another important phenomenon which requires to be taken into consideration in the reduction of astronomical observations. Although light travels with the enormous velocity of 186,660[a] miles per second—a speed so great, that for all practical terrestrial purposes we may consider it to be propagated instantaneously; yet the astronomer, who has to deal with distances of millions of miles, is obliged to be more precise. A simple illustration will shew this: if we take the mean distance of our globe from the Sun at 92,890,000 miles, and consider that light travels at the rate of 186,150 miles per second, we may ascertain by a simple arithmetical process that the time occupied by a ray of light in reaching us from the Sun is $8^m\ 19^s$, so that in point of fact, in looking at the Sun at a given moment, we do not see it shining as it is, but as it was $8^m\ 19^s$ previously. If the Earth were at rest, this would be a

[a] A. Cornu (*Proceedings of the Roy. Inst.*, vol. vii. p. 472, May 1875) makes it 186,660 miles, but it is probably somewhat less. Other values obtained experimentally are: Helmert, 299,990 kilometres; Michelson, 299,910 kilometres; Young and Forbes, 301,382 kilometres. For a comprehensive review, historical and practical, of the whole subject of the velocity of light, see a Memoir by Newcomb in *Astron. Papers prepared for American Naut. Alm.*, vol. ii. part III.

trivial matter; but as the Earth is in motion, it follows that when the solar ray enters the eye of a person on its surface, he will be some way removed from the point in space at which he was situated when the ray left the Sun; he will consequently see that luminary behind the true place it actually occupies when the ray enters his eye. In the course of $8^m\ 19^s$ the Earth will have advanced in its orbit 20·492″; this quantity is called the *Constant of Aberration* [b]. Aberration may be defined to be a phenomenon resulting from the combined effect of the motion of

Fig. 175.



ABERRATION.

light and of the motion of the Earth in its orbit [c]. Suppose a ball let fall from a point P above the horizontal line AB, and a tube, of which A is the lower extremity, placed to receive it; if the tube were fixed the ball would strike it on the lower side, but if the tube were carried forwards in the direction AB, with a velocity properly adjusted at every instant to that of the ball while *preserving its inclination* to the horizon, so that when the ball in its natural descent reached B the tube would have been carried into the position BQ, it is evident that the ball throughout its whole descent would be in the tube; and a spectator

[b] Baily's value is 20·419″; W. Struve's is 20·445″; C. A. F. Peters's, 20·425″, 20·503″, and 20·481″; Lindenau's, 20·448″; Lundahl's, 20·550″; Maclear's, 20·53″; Main's, 20·335″; Nyrén's, 20·492″. Struve's was long considered the best, but Nyrén's is now accepted as such.

[c] See a paper by Challis in *Phil. Mag.*, 4th ser., vol. ix. p. 430. June 1855.

referring to the tube the motion of the ball, and carried along with the former, unconscious of its motion, would fancy that the ball had been moving in an inclined direction and had come from Q. The following similes are frequently used to exemplify aberration: a shower of rain descending perpendicularly will appear to fall in its true direction to a person at rest, but if he move rapidly through it, it will meet him in a slanting direction: in other words, it will have an apparent as well as a real motion. A cannon-ball fired from a shore-battery at a vessel passing up a river will not pass through the ship in a line coincident with the direction of the ball, but will emerge on the other side at a point differing more or less from this line; the amount of the variation, however, will depend on the relative velocities of the ball and ship at the time. If we suppose the cannon-ball to represent light, and the movement of the ship the motion of the Earth in its orbit, we have an excellent illustration of the phenomenon of aberration [d].

This unquestionably grand discovery resulted more immediately from an attempt to detect stellar parallax. Although the facts revealed by the invention of the telescope and the discovery of gravitation had the effect of establishing beyond doubt the truth of the Copernican theory of the Universe, still it was much to be desired that some more *direct* proof should be adduced. The absence of any appreciable change in the positions of the fixed stars when examined from opposite sides of the Earth's orbit, was one of the earliest, and at the same time one of the most serious, arguments brought against the system of Copernicus; as it was always considered that the detection of such a change would furnish an irresistible proof that the Earth was not at rest, and consequently was not the centre of the system. The first observation which ultimately led to the discovery of aberration was made by Hooke, who selected the star γ Draconis as suitable for the detection of annual parallax [e]. After observing it carefully

[d] See Airy's *Lectures on Astronomy*, p. 188.

[e] Hooke considered it desirable to observe stars as near the zenith as possible, in order to avoid the effects arising from any uncertainty as to the value of re-

at different seasons of the year, he came to the conclusion that it had a sensible parallax. It was soon found, however, that the star was subject to a displacement in a direction contrary to that which ought to have resulted had the star been affected by parallax only; and it was for the purpose of endeavouring to ascertain the physical cause of this strange phenomenon that Bradley was led to provide himself with an instrument, that he might more conveniently study the subject of parallax and anything that might arise connected therewith. His observations completely confirmed those of Hooke, and "at length the happy idea occurred to him, that the phenomenon might be completely accounted for by the gradual propagation of light combined with the motion of the Earth in its orbit."

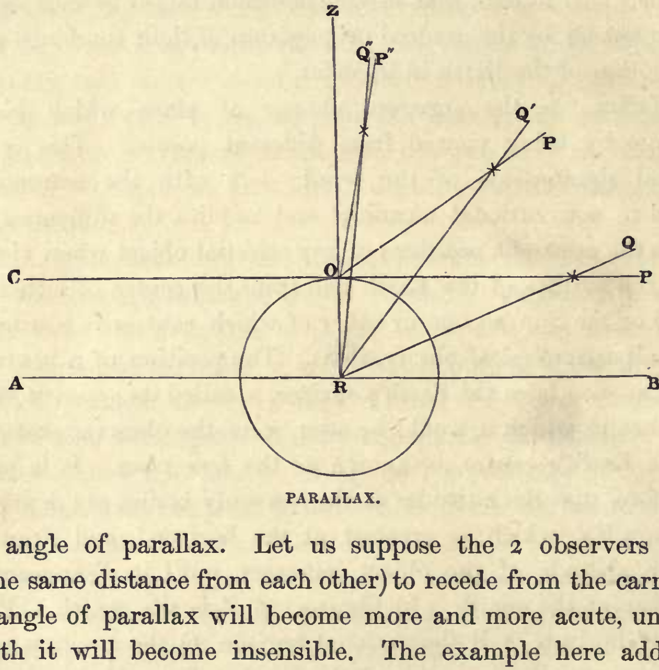
Parallax "is the apparent change of place which bodies undergo by being viewed from different points." This is the general signification of the word; but with the astronomer it has a conventional meaning, and implies the difference between the apparent positions of any celestial object when viewed from the surface of the Earth and from the centre of either the Earth or the Sun, to one or other of which centres it is usual to refer all astronomical observations. The position of a heavenly body, as seen from the Earth's surface, is called its *apparent place;* and that in which it would be seen, were the observer stationed at the Earth's centre, is known as the *true place.* It is plain, therefore, that the altitudes of the heavenly bodies are depressed by parallax, which is greatest at the horizon [f], and decreases as the altitude of the object increases, until it disappears altogether at the zenith. In Figure 176, Z is the zenith, C P the visible horizon, A B the rational horizon, O the position of an observer, and R the centre of the Earth. From O the observer will see the stars projected on the sky at P, P′, and P″, (*apparent*

fraction; and γ Draconis happened to be the only bright star passing within a few minutes of the zenith of Gresham College, where his instrument was erected. (*Attempt to prove the Motion of the Earth*, p. 7.)

[f] This is the case because imaginary lines, drawn from the object to the observer, and to the centre of the Earth respectively, will then have the greatest possible inclination to each other.

places); but, referred to the centre of the Earth, the points of projection will be Q, Q′, and Q″ (*geocentric places*). The general nature of parallax may be readily understood by supposing 2 persons placed each at the end of a straight line, to look at a carriage standing in front of a house at the distance (say) of 50 yards from each station. It is evident that the carriage will appear to each spectator projected upon different parts of the house. The angle which this difference of position gives rise to, that is to say the angle formed by the 2 lines of direction, is

Fig. 176.



PARALLAX.

the angle of parallax. Let us suppose the 2 observers (still at the same distance from each other) to recede from the carriage; the angle of parallax will become more and more acute, until at length it will become insensible. The example here adduced may be applied to the heavenly bodies[g].

Of all the heavenly bodies, the Moon is that of which the horizontal parallax is the most considerable, because that luminary is the nearest to the Earth. It is found in the following way:—

[g] A very good popular exposition of the principles involved in the measurement of parallaxes by astronomers will be found in Guillemin's *Soleil*, pp. 84–9, 2nd French Edition.

Suppose that 2 astronomers take their stations on the same meridian, one South of the equator, as at the Cape of Good Hope, and the other North of the equator, as at Berlin, which 2 places lie nearly on the same meridian: the observers would severally refer the Moon to different points on the face of the sky—the Southern observer carrying it farther to the North, and the Northern observer farther to the South, than its true place as seen from the centre of the Earth. The observations thus made at the 2 places furnish the materials for calculating, by means of trigonometry, the value of the horizontal parallax of the Moon, from which we can deduce both its distance and real magnitude. The parallax thus obtained is called the *diurnal*, or geocentric, a term used to distinguish such parallax from *annual*, or heliocentric, parallax. And in general it may be stated that these terms express the angular displacement of a celestial object according as it is viewed from the Earth or the Sun respectively: in particular, however, it denotes half the angle formed by 2 imaginary lines drawn from each extremity of the diameter of the Earth's orbit to a fixed star. But this angle is generally too small to be appreciable. It was this fact of the non-detection of annual parallax which for a long period of time prior to the invention of the telescope formed a great obstacle to the progress of Copernican opinions relative to the system of the universe.

The Sun, Moon, and planets, though separated from us by millions of miles, are affected by parallax to a small but nevertheless appreciable amount. With but a few exceptions, however, this is not the case with the fixed stars; for in only a very few instances has parallax been detected, and, so far as is yet known, the star *nearest* to us is α Centauri, whose parallax is equal to only 0·75″, which is equivalent to many billions of miles, as will appear hereafter[h].

We may obtain some idea of the importance attaching to a

[h] As illustrating the delicacy of observations of this kind, the following remark of Airy's is instructive: "An angle of 2″ is that in which a circle $\frac{6}{10}$ of an inch in diameter would be seen at the distance of a mile. This is [that of] the star which shows the *greatest parallax of all.*" *Lectures on Ast.*, p. 196.

correct determination of the parallax of an object by an inspection of the following table :—

If the Sun's horizontal parallax were 11″, the mean distance of the following planets from the Sun in miles would be :—

The Earth.	*Mars.*	*Jupiter.*	*Saturn.*
75,000,000	114,276,750	390,034,500	715,504,500
If the Sun's parallax were 10″, the above distance would become :—			
82,000,000	124,942,580	426,478,720	782,284,920
Errors arising from a mistake of only 1″ :—			
7,000,000	10,665,830	36,444,220	66,780,420[i]
If the Sun's parallax be taken at 8·80, the distances will be :—			
92,890,000	141,536,000	483,288,000	886,065,000

It is only within comparatively the last few years that the efforts of astronomers to detect stellar parallax have been attended with any amount of success. The discovery of planetary parallax is of course of older date. Pliny considered such investigations to be but little better than madness, and Riccioli remarks, "Parallaxis et distantia stellarum fixarum, non potest certa et evidenti observatione humanitùs comprehendi." Leonard Digges, an old English writer, however, seems to have found no difficulty in the matter; he gives the following table of distances, which, however, unfortunately for his reputation, has turned out to be seriously incorrect. He adds, "Here demonstracion might be made of the distaunce of these orbes, but that passeth the capacity of the common sort." These are his results [k] :—

	Myles
"From the Earth to the Moone	15,750
From the Moone to Mercury	12,812
From Mercury to Venus	12,812
From Venus to the Sunne	23,437½
From the Sunne to Mars	15,725
From Mars to Jupiter	78,721
From Jupiter to Saturne	78,721
From Saturne to the Firmament	120,485."

Whence it follows, according to Digges, that the distance from London to the stars is exactly 358,463½ miles!

[i] Ferguson's *Astronomy*, p. 76, 2nd Edition, London, 1757.

[k] *Prognostication Euerlastinge*, 2nd ed. 1576, fol. 16.

CHAPTER V.

REFRACTION AND TWILIGHT.

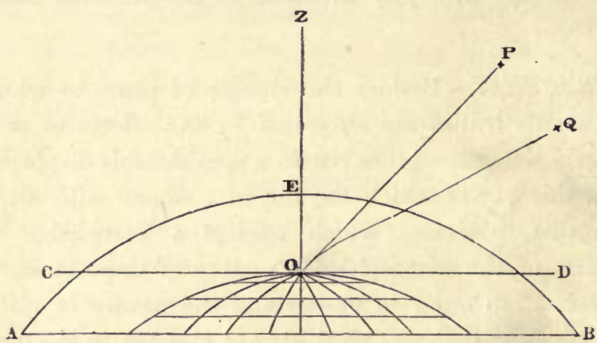
Refraction.—Its nature.—Importance of a correct knowledge of its amount.—Table of the correction for Refraction.—Effect of Refraction on the position of objects in the horizon.—History of its discovery.—Twilight.—How caused.—Its duration.

REFRACTION.—Besides the change of place to which the heavenly bodies are subjected by the effects of parallax, atmospheric refraction gives rise to a considerable displacement; and it is this power which the air, in common with all transparent media, possesses, which renders a knowledge of the constitution of the atmosphere a matter of importance to the astronomer. "In order to understand the nature of refraction we must consider that an object always appears in the direction in which the *last* ray of light comes to the eye. If the light which comes from a star were bent into 50 directions before it reached the eye, the star would nevertheless appear in a line described by the ray nearest the eye. The operation of this principle is seen when an oar, or any stick, is thrust into the water. As the rays of light by which the oar is seen have their direction changed as they pass out of water into air, the apparent direction in which the body is seen is changed in the same degree, giving it a bent appearance—the part below the water having apparently a different direction from the part above[a]."

[a] Olmsted, *Mechanism of the Heavens*, p. 94. Edinburgh edition. In Sir J. Herschel's *Outlines of Ast.* (pp. 27 *et seq.*) there will be found a useful summary of information concerning refraction.

The direction of this refraction is determined by a general law in optics, that when a ray of light passes out of a rarer into a denser medium—*e.g.* out of air into water, or out of space into the Earth's atmosphere—it is bent *towards* a perpendicular to the surface of the medium; but when it passes out of a denser into a rarer medium, it is bent *from* the perpendicular. Inasmuch then as we see any object in the direction in which the rays emanating from it reach the eye, it follows that the effect of refraction is to make the apparent altitude of a heavenly body appear greater than the true altitude; so

Fig. 177.



REFRACTION.

that for example any object situated actually *in* the horizon will appear *above* it. Indeed, some objects that are actually below the horizon, and which would be otherwise invisible were it not for refraction, are thus brought into sight. It was in consequence of this that on April 20, 1837, the Moon rose eclipsed before the Sun had set; and other like instances may be conceived.

In Fig. 177, Z is the zenith, C D the visible horizon, A B a parallel of latitude, A E B the boundary of the Earth's atmosphere. Then the light of the star Q will, to the observer at O, seem to come from the point P.

A correct determination of the exact amount of atmospheric refraction, or the angular displacement of a celestial object at any altitude, is a very important, but a very difficult subject of inquiry, owing to the fact that the density of any stratum of air (on which its refractive power depends) is affected by the operation of meteorological phenomena with which we are at present but very imperfectly acquainted. Thus, the amount of refraction at any given altitude depends not only on the density but also on the thermometric and hygrometric conditions of the air through which the visual ray passes. And although we know the general fact that the barometric pressure [b] and the temperature [c] constantly diminish as we rise from the Earth's surface, yet the law of this diminution is not fully ascertained. In consequence of our ignorance on these points, some degree of uncertainty is introduced into the determination of the amount of refraction, which affects astronomical observations involving extremely minute quantities. Nevertheless it must be remembered that inasmuch as the total amount of refraction is never considerable, and in most cases very small, it can be so nearly estimated as to offer no serious impediment to the astronomer.

Tables are in use [d], constructed partly from observation and partly from theory, by means of which we can ascertain approximately the mean refraction at any given altitude; additional rules being given by which this average refraction may be corrected according to the state of the air at the time of observation. At the zenith, or at an altitude of 90°, there is no refraction whatever, objects being seen in the position which they would

[b] Since the barometer rises with an increase in the weight and density of the air, its rise is coincident with an augmentation, and its fall with a decrease, of refraction. It will be tolerably near the truth if we assume that the refraction at any given altitude is increased or diminished by $\frac{1}{300}$ of its mean amount for every 10th of an inch by which the barometer exceeds or falls short of 30 inches.

[c] Also as an increase of temperature causes a decrease of density, it follows that the rise of the thermometer diminishes the effect of refraction, the barometer remaining stationary. We may assume that the refraction at any given altitude is increased or diminished by $\frac{1}{420}$ of its mean amount for each degree by which the thermometer exceeds or falls short of the mean temperature of 55° Fahr.

[d] See Vol. II, *post*.

have were the Earth devoid of any atmosphere at all. In descending from the zenith towards the horizon, the refraction constantly increases, objects near the horizon being displaced in a greater degree than those at high altitudes. Thus the refraction, which at an altitude of 45° is only equal to 57″, at the horizon increases to nearly 35′. The rate of the increase at high altitudes is nearly in proportion to the tangent of the apparent angular distance of the object from the zenith; but in the vicinity of the horizon this rule ceases to hold good, and the law becomes much more complicated in its expression. Since the mean diameter both of the Sun and Moon is about 32′, it follows that, when we see the lower edge of either of these luminaries apparently just *touching* the horizon, in *reality* its whole disc is completely *below* it, and would be altogether hidden by the convexity of the Earth were it not for refraction.

It is under these circumstances that one of the most curious effects resulting from atmospheric refraction may often be noticed, namely the somewhat oval outline presented by the Sun and Moon when near the horizon. This arises from the unequal refraction of the upper and lower limbs. The lower limb being nearer the horizon, is more affected by refraction, and consequently is raised in a greater degree than the upper limb, "the effect being to bring the two limbs apparently closer together by the difference of the two refractions. The form of the disc is therefore affected as if it were pressed between two forces, one acting above and the other below, tending to compress its vertical diameter, and to give it the form of an ellipse, the lesser axis of which is vertical and the greater horizontal."

The dim and hazy appearance of objects in the horizon is not only occasioned by the rays of light having to traverse a greater thickness of atmosphere (because their direction is oblique), but also from their having to pass through the lower and denser part. "It is estimated that the solar light is diminished 1300 times in passing through these lower strata, and we are thereby enabled to gaze upon the Sun, when setting, without being dazzled by his beams." Or, as Bouguer put it, the Sun's brilliancy at 40° above the horizon is 1000 times greater than it is at 1°.

"The dilated size (generally) of the Sun or Moon when seen near the horizon beyond what they appear to have when high up in the sky, has nothing to do with refraction. It is an illusion of the judgment, arising from the terrestrial objects interposed, or placed in close comparison with them [e]. In that situation we view and judge of them as we do of terrestrial objects—in detail, and with an acquired habit of attention to parts. Aloft we have no associations to guide us, and their insulation in the expanse of the sky leads us rather to under-value than to over-rate their apparent magnitudes. Actual measurement with a proper instrument corrects our error, without however dispelling our illusion. By this we learn that the Sun, when just on the horizon, subtends at our eyes almost exactly the same, and the Moon a materially *less* angle than when seen at a great altitude in the sky, owing to its greater distance from us in the former situation as compared with the latter [f]." Guillemin remarks that if the Moon, when in the horizon, be looked at through a tube, the illusion will disappear.

Claudius Ptolemy was the first who remarked that a ray of light proceeding from a star to the Earth undergoes a change of direction in passing through the atmosphere [g]. He moreover stated that the displacement is greatest at the horizon, diminishes as the altitude increases, and finally vanishes altogether

[e] This explanation of Sir J. Herschel's has been disputed, but its general correctness is rendered highly probable by the fact that the apparent size of a balloon varies in precisely the same way, according as it is high up in the air or near the horizon. See some remarks by Stroobant quoted in *Observatory*, vol. viii. p. 130, April, 1885. This writer thinks that the loss of brilliancy suffered by the Sun and Moon when low down towards the horizon has much to do with the phenomenon, but that it is mainly due to some physiological cause, connected with the direction of vision, which is worthy of further and special study.

[f] Sir J. Herschel, *Outlines of Ast.*, p. 35.

[g] *Almag.*, lib. vii. cap. 6.

at the zenith – an assertion which we have already seen to be perfectly correct. In the 16th century Tycho Brahe also investigated the subject of refraction; and his results, though by no means so accurate as those of Ptolemy, are interesting from the fact that they were the first which were reduced to the form of a Table. Since this period many astronomers have devoted their attention to the matter, and the Tables now in most general use are those of Bessel.

Twilight.—This is another phenomenon depending on the agency of the atmosphere with which the Earth is surrounded. It is due partly to refraction and partly to reflection, but chiefly to the latter cause. After sunset the Sun still continues to illuminate the clouds and upper strata of the air, just as it may be seen shining on the tops of hills long after it has disappeared from the view of the inhabitants of adjacent plains. The air and clouds thus illuminated reflect back part of the light to the surface beneath them, and thus produce, after sunset and before sunrise, in a degree more or less feeble according as the Sun is more or less depressed, that which we call "twilight." Immediately after the Sun has disappeared below the horizon all the clouds in the vicinity are so highly illuminated as to be able to reflect an amount of light but little inferior to the direct light of the Sun. As the Sun, however, sinks lower and lower, less and less of the visible atmosphere receives its light, and consequently less and less of it is reflected to the Earth's surface surrounding the position where the observer is stationed, until at length, though by slow degrees, all reflection is at an end, and night ensues. The same thing occurs before sunrise; the darkness of night gradually giving place to the faint light of dawn, until the Sun appears above the horizon and produces the full light of day.

The duration of twilight is usually reckoned to last until the Sun's depression below the horizon amounts to 18°: this, however, varies: in the Tropics a depression of 16° or 17° is sufficient to put an end to the phenomenon, but in England a depression of 17° to 21° is required. The duration of twilight differs in different latitudes; it varies also in the same latitude at different seasons of the year, and depends in some measure on the meteorological condition of the atmosphere. Strictly speaking, in the latitude of Greenwich there is no true night from May 22 to July 21, but constant twilight from sunset to sunrise. Twilight reaches its minimum 3 weeks before the vernal equinox and 3 weeks after the autumnal equinox, when its duration is $1^h\ 50^m$. At midwinter it is longer by about 17^m, but the augmentation is frequently not perceptible, owing to the greater prevalence of clouds and haze at that season of the year, which intercept the light and hinder it from reaching the Earth. The duration is least at the equator ($1^h\ 12^m$), and increases as we approach the Poles, for at the former there are 2 twilights every 24 hours, but at the latter only 2 in a year, each lasting about 50 days. At the North Pole the Sun is below the horizon for 6 months[h]; but from January 29 to the vernal equinox, and from the autumnal equinox to Nov. 12, the Sun is less than 18° below the horizon: so that there is twilight during the whole of these intervals, and thus the length of the actual night is reduced to 2½ months. The length of the day in these regions is about 6 months, during the whole of which time the Sun is constantly above the horizon. The general rule is, *that to the inhabitants of an oblique sphere the twilight is longer in proportion as the place is nearer the elevated pole*[i].

Under some circumstances a secondary twilight may be noticed, "consequent on a re-reflection of the rays dispersed through the atmosphere in the primary one. The phenomenon seen in the clear atmosphere of the Nubian Desert, described by travellers under the name of the 'After-glow,' would seem to arise from this cause[k]."

The "Astronomical" Twilight is that Twilight which has reference to the visibility and extinction of the smaller stars.

[h] This is not quite literally 6 months owing to the operation of refraction.

[i] A valuable memoir on twilight, by J. F. J. Schmidt, will be found in *Ast. Nach.*, vol. lxiii. No. 1495, Oct. 14, 1864. An abstract of it is given in the *Intell. Obs.*, vol. vii. p. 135, March 1865.

[k] Sir J. Herschel, *Outlines of Ast.*, p. 34.

The following is a table of its duration for different seasons and latitudes:—

Latitude, N. or S.	Duration.		
	Winter Solstice.	Equinoxes.	Summer Solstice.
	h. m.	h. m.	h. m.
0	1 19	1 12	1 19
5	1 19	1 12	1 20
10	1 19	1 13	1 21
15	1 20	1 15	1 24
20	1 23	1 17	1 28
25	1 26	1 20	1 33
30	1 30	1 24	1 41
35	1 35	1 29	1 52
40	1 43	1 35	2 9
45	1 53	1 44	2 39
50	2 6	1 55	Twilight lasts all night.
55	2 26	2 10	Twilight lasts all night.
60	2 57	2 33	Twilight lasts all night.
65	4 3	3 8	Twilight lasts all night.

BOOK IV.

COMETS.

CHAPTER I.

GENERAL REMARKS.

Comets always objects of popular interest, and sometimes of alarm.—Usual phenomena attending the development of a Comet.—Telescopic Comets.—Comets diminish in brilliancy at each return.—Period of revolution.—Density.—Mass.—Lexell's Comet.—General influence of Planets on Comets.—Special influence of Jupiter.—Comets move in 1 of 3 kinds of orbits.—Element of a Comet's orbit.—For a parabolic orbit, 5 in number.—Direction of motion.—Eccentricity of an elliptic orbit.—The various possible sections of a cone.—Early speculations as to the paths in which Comets move.—Comets visible in the daytime.—Breaking up of a Comet into parts.—Instance of Biela's Comet.—Liais's observations of Comet iii. 1860.—Comets probably self-luminous.—Existence of phases doubtful.—Comets with Planetary discs.—Phenomena connected with the tails of Comets.—Usually in the direction of the radius vector.—Secondary Tails.—Vibration sometimes noticed in tails.—Olbers's hypothesis.—Transits of Comets across the Sun's disc.—Variation in the appearance of Comets exemplified in the case of that of 1769.—Transits of Comets across the Sun.

THE heavenly bodies which will now come under our notice are amongst the most interesting with which the astronomer has to deal. Frequently appearing suddenly in the nocturnal sky, and often having attached to them tails of immense size and brilliancy, comets were well calculated in the earlier ages of the world to attract the attention of all, and to excite the fear of many. It is the unanimous testimony of history, during a period of upwards of 2000 years, that comets were always considered to be peculiarly "ominous of the wrath of Heaven, and as harbingers of wars and famines, of the dethronement of monarchs, and the dissolution of empires." I shall hereafter examine this question at greater length. Suffice it for me here to quote the words of the Poet, who speaks of—

> "A Blazing Star,
> Threatens the World with Famin, Plague, and War;
> To Princes, death; to Kingdoms, many crosses;
> To all Estates, ineuitable Losses;
> To Heard-men, Rot; To Ploughmen, haplesse Seasons;
> To Saylors, Storms; to Cities, ciuil Treasons [a]."

However little attention might have been paid by the ancients to the more ordinary phenomena of nature (which, however, were very well looked after), yet certain it is that comets and total eclipses of the Sun were not easily forgotten or lightly passed over; hence the aspects of remarkable comets seen in

Fig. 178.

TELESCOPIC COMET WITHOUT A NUCLEUS.

Fig. 179.

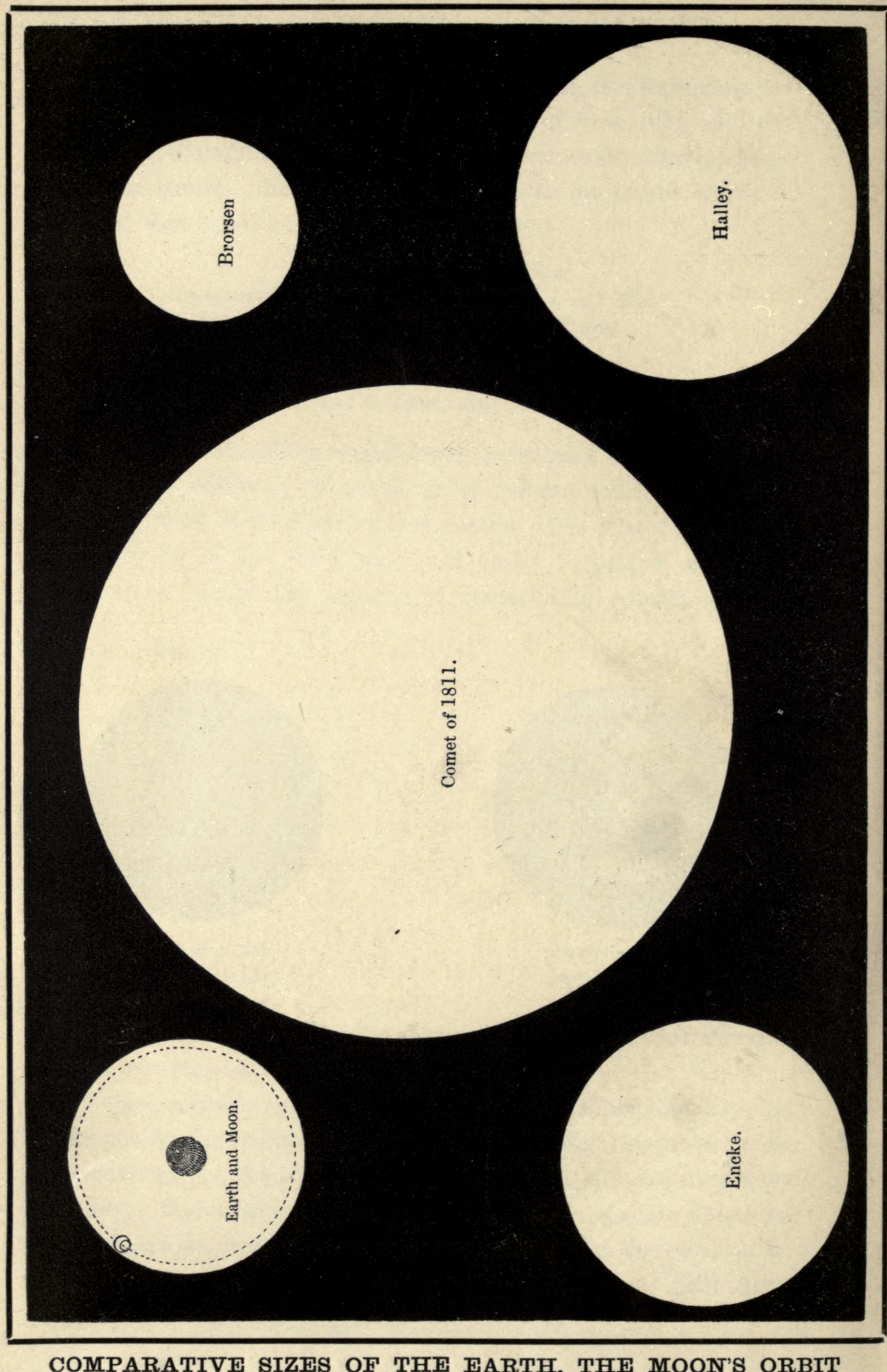
TELESCOPIC COMET WITH A NUCLEUS.

olden times have been handed down to us, often with circumstantial minuteness.

A comet usually consists of 3 parts, developed, it may be, somewhat in the following manner:—A faintly luminous speck is discovered by the aid of a good telescope; the size increases gradually; and after some little time a *nucleus* appears—that is, a part which is more condensed in its light than the rest, and is sometimes circular, sometimes oval, and sometimes (but very

[a] Du Bartas, trans. J. Sylvester, 1621, p. 33.

Fig. 180. *Plate* XXIII.



COMPARATIVE SIZES OF THE EARTH, THE MOON'S ORBIT AND CERTAIN COMETS, NAMED.

rarely) presents a radiated appearance. Arago remarked that this nucleus is generally eccentrically placed in the head, lying towards the margin nearest the Sun. Eddie noticed that the nucleus of Fabry's comet of 1886 was of a ruddy brown colour [b]. Both the size and the brilliancy of the object progressively increase; the *coma*, or cloud-like mass around the nucleus, becomes less regular; and a tail begins to form, which becomes fainter as it recedes from the body of the comet. This tail increases in length so as sometimes to spread across a large portion of the heavens; sometimes there are more tails than one, and occasionally the tail is much narrower in some parts than in others. The comet approaches the Sun in a curvilinear path, which frequently differs but little from a right line. It generally crosses that part of the heavens in which the Sun is situated so near the latter body as to be lost in its rays; but it emerges again on the other side, frequently with increased brilliancy and increased length of tail. The phenomena of disappearance are then not unlike those which marked the original appearance but in the reverse order.

In magnitude and brightness comets exhibit great diversity: at rare intervals one appears which is so bright as to be visible in the daytime; but the majority are quite invisible to the naked eye and need more or less optical assistance. These latter are usually called *telescopic comets*. The appearance of the same comet at different periods of its return is so varying that we can never certainly identify a given comet with any other by any mere physical peculiarity of size or shape until its "elements" have been calculated and compared. It is now known that "the same comet may, at successive returns to our system, sometimes appear tailed, and sometimes without a tail, according to its position with respect to the Earth and the Sun; and there is reason to believe that comets in general, for some unknown cause, decrease in splendour in each successive revolution [c]."

Fig. 180 represents the comparative diameters of the heads of 4 well-known comets as measured on particular occasions. The

[b] *Month. Not.*, vol. xlvi. p. 456, June 1886. [c] Smyth, *Cycle*, vol. i. p. 235.

woodcut is drawn to scale, but it must not be inferred that there is any permanence in the sizes here indicated.

The periods of comets in their revolutions vary greatly, as also do the distances to which they recede from the Sun. Whilst the orbit of Encke's comet is contained within that of Jupiter, the orbit of Halley's extends beyond that of Neptune. Some comets indeed proceed to a much greater distance than this, whilst others are supposed to move in curves which do not, like the ellipse, return into themselves. In this case they never come back to the Sun. These orbits are either parabolic or hyperbolic.

The density, and also the *mass*, of comets is exceedingly small, and their tails consist of matter of such extreme tenuity that even small stars are visible through them—a fact first recorded by Seneca. That the matter of comets is exceedingly rare is sufficiently proved by the fact that they have at times passed very near to some of the planets without disturbing in any appreciable degree the motions of the said planets. Thus the comet of 1770 (Lexell's) in its advance towards the Sun, became entangled amongst the satellites of Jupiter, and remained near them for 4 months, without in the least affecting them so far as we know. It can therefore be shown that this comet's mass could not have been so much as $\frac{1}{5000}$ that of the Earth. The same comet also came very near to the Earth on July 1—its distance from it at 5^h on that day being about 1,400,000 miles—so that had its matter been equal in quantity to that of the Earth it would, by its attraction, have caused our globe to move in an orbit so much larger than it does at present that it would have increased the length of the year by $2^h\ 47^m$, yet no sensible alteration took place. The comet of 837 remained for 4 days within 3,700,000 miles of the Earth without any untoward consequences. Very little argument, therefore, suffices to show the absurdity of the idea of any danger happening to our planet from the advent of any of these wandering strangers. Indeed, instead of comets exercising any influence on the motions of planets, there is the most conclusive evidence that the converse is the case—that planets influence comets. This fact is strikingly exemplified in the history of the comet of 1770, just mentioned. At its appearance it was found to have an elliptical orbit, requiring for a complete revolution only 5½ years; yet although this comet was a large and bright one, it had never been observed before, and has moreover never been seen since; the reason being that the influence of the planet Jupiter, in a short period, completely changed the character of its path. "Du Séjour has proved that a comet, whose mass is equal to that of the Earth, which would pass at a distance of 37,500 miles only, would extend the length of the year to $367^d\ 16^h\ 5^m$, and could alter the obliquity of the ecliptic to the extent of 2°. Notwithstanding its enormous mass and the smallness of its distance, such a body would then produce upon our globe only one kind of revolution,—that of the calendar[d]."

Fig. 181 will illustrate, almost without the necessity of any written description, the influence of Jupiter on the group of periodical comets which have come within its reach. These comets, arranged in the order of their aphelion distances, are as follows:—

	Radii of Earth's orbit.
Encke	4·1
Tempel's Second (1873, ii.)	4·7
Tempel's First (1867, ii.)	4·8
JUPITER	4·9 to 5·5
Tempel-Swift (1869, iii.)	5·1
Brorsen	5·6
Winnecke	5·6
D'Arrest	5·8
Faye	5·9
Biela	6·2

And it is probable that some other comets ought now to be added to this list; *e.g.*, Finlay's (1886, vii.), Wolf's (1884, iii.), and Denning's (1881, v.).

A comet may move in either an elliptic, parabolic, or hyperbolic orbit; but for reasons with which mathematical readers are acquainted, no comet can be periodical which does not follow an elliptic path. In consequence, however, of the comparative

[d] Arago, *Pop. Ast.*, vol. i. p. 642, Eng. ed.

facility[e] with which the parabola can be calculated, astronomers are in the habit of applying that curve to represent first of all the orbit of any newly-discovered body. Parabolic "elements" having been obtained, a search is then made through a catalogue of comets, to see whether the new elements bear any resemblance

Fig. 181.

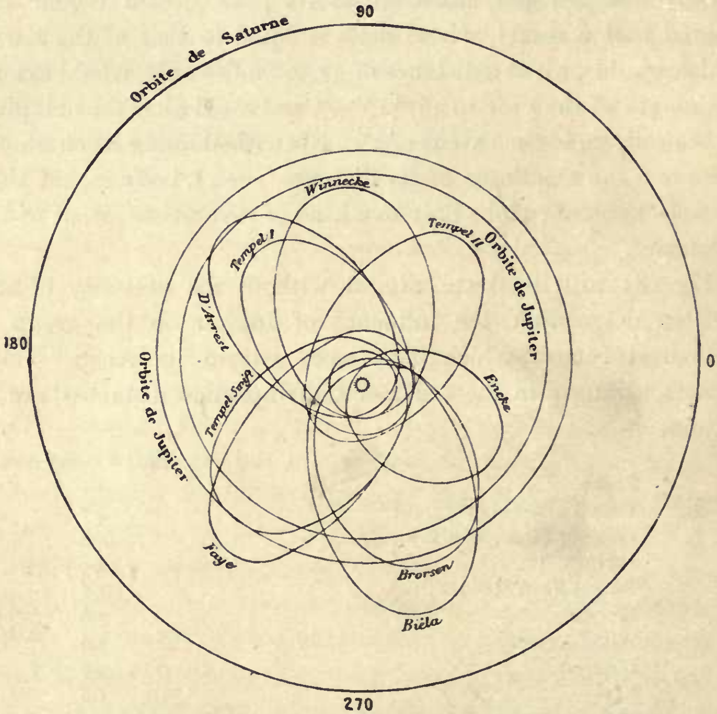


DIAGRAM ILLUSTRATING THE INFLUENCE OF JUPITER ON COMETS.

to those of any object which has been previously observed; if so, calculations for an elliptic orbit are undertaken, and a period deduced.

When a comet is discovered the first question asked about it by the amateur astronomer is, "When and where can we see it, and how long will it last?" and by the professional astronomer,

[e] To compute elliptic elements for a comet or a planet will take, even an experienced calculator, several days of very hard work. An approximation may however be obtained by a graphical process such as that described in Chap. VI (*post*).

"What are its elements?" The answer to be given to the first question always depends upon the answer given to the last question. To the majority of amateurs these elements are almost unintelligible, and even to adepts they often convey but a vague idea of the true form and position of the orbit. The best way to realize their exact import is by making a model[f].

The orbits of all comets, planets, and binary stars are conic sections whose size, form, and position in space are defined by quantities called "elements," which, for brevity, are usually designated by the following symbols:—

T = Moment of the body's Perihelion Passage or nearest approach to the Sun[g].

λ = Longitude at an Epoch given.

π = Longitude of the Perihelion or the longitude of the body when it reaches that point. In the case of a comet (or planet), this is measured along the ecliptic from the vernal equinox to the comet's ascending node, and thence along the comet's (or planet's) orbit to its perihelion; in the case of the Earth, it is measured along the ecliptic from the vernal equinox to the perihelion.

☊ = Longitude of the Ascending Node of the body's orbit as seen from the Sun (or Primary); measured on the ecliptic, from the vernal equinox to the ascending node of the orbit.

ι = Inclination of the plane of the orbit to the plane of the ecliptic.

ϵ = Eccentricity of the orbit, sometimes given in parts of radius of the Earth's orbit, sometimes in seconds of arc, and sometimes as an angle, ϕ. Parts of radius are most convenient, and seconds of arc may be reduced to that unit by dividing them by 206,265″. When ϕ is given, then it is to be understood that $\epsilon = \sin. \phi$.

[f] For instructions how to do this see an article by Professor Harkness in the *Sidereal Messenger*, vol. vi. p. 329, Dec. 1887. From the introduction to that article the next few paragraphs are taken with verbal alterations.

[g] In the case of a binary star, of the nearest approach of the companion star to the principal star, in such case called, not the *perihelion*, but the *peri-astron* passage.

$q =$ Perihelion distance of the body; expressed in terms of the mean radius of the Earth's orbit as unity.

For a parabolic orbit ϵ is always 1·0 (or unity), and in that case the elements are frequently given by stating T, ω, ☊, ι, and log. q. Here π has been replaced by

$$\omega = \pi - ☊, \tag{1}$$

which is counted on the comet's orbit, backward, from the perihelion to the ascending node; and the perihelion will lie on the northern or southern side of the ecliptic according as ω is less or greater than 180°.

As π and ☊ are counted from the vernal equinox, and ι is measured from the plane of the ecliptic, these quantities necessarily refer to a particular equinox, and this is always specified.

It was long customary to measure longitudes in comets' orbits in the direction of the Earth's motion, to limit ι to the first quadrant, and to specify the direction of the comet's motion, whether direct or retrograde; but many foreign astronomers now follow Gauss in regarding retrograde motion as a result of the inclination passing into the second quadrant, and in accordance with that view they measure a comet's longitude always in the direction of its own motion, and permit ι to take any value between 0° and 180°. The circumstance that ι is measured at the ascending node limits its range to the first and second quadrants, for if it were to pass into the third or fourth quadrant the ascending node would be converted into a descending one. For a comet having direct motion the numerical values of the elements are the same in Gauss's system as in the old system, but for a comet having retrograde motion they are different, and in that case, if their values according to the old system are designated by a subscript o, the equations requisite for passing from the old to the Gaussian system are:—

$$i = 180° - i_0 \qquad \omega = 360° - \omega_0 = -\omega_0$$

$$☊ = ☊_0 \qquad \pi = 2☊_0 - \pi_0.$$

There is frequently much confusion respecting the angles π and ω, and it is important to have a clear understanding of the relations of ω to π and ☊. In the old system of elements π is measured from the vernal equinox, along the ecliptic in the direction of the Earth's motion, to the ascending node of the comet, and thence along the comet's orbit, *still in the direction of the Earth's motion*, to the comet's perihelion. In Gauss's system π is measured from the vernal equinox, along the ecliptic in the direction of the earth's motion, to the ascending node of the comet, and thence along the comet's orbit, *in the direction of the comet's motion*, to the comet's perihelion. These definitions may perhaps be elucidated by the following statement. Imagine a perpendicular to the plane of the ecliptic, erected from the Sun. Then to an observer situated North of the ecliptic in that perpendicular, the motion of the Earth will be contrary to the hands of a clock, and longitudes in the Earth's orbit will increase in that direction. Now consider a comet's orbit; imagine a perpendicular affixed to it in such a way that when the inclination of the orbit to the plane of the ecliptic is ι, the inclination of the perpendicular shall be $(\iota + 90°)$, and suppose an observer so situated in the perpendicular that when $\iota = 0°$ he shall be North of the ecliptic. Then, according to the old system of elements, for all possible values of ι the observer will remain North of the ecliptic, and the motion of the comet will appear to him as contrary to the hands of a clock when direct, and with the hands of a clock when retrograde; but according to Gauss's system he will be North of the ecliptic when ι is less than 90°, South of it when ι is greater than 90°, and to him the apparent direction of the comet's motion will always be contrary to the hands of a clock. Whichever system is adopted, from this point of view π will always increase contrary to the clock, and to find the intersection of the plane of the comet's orbit with the plane of the ecliptic, or, in other words, the line of the nodes, he must set off ω in the direction of the hands of a clock, from the perihelion of the orbit.

The motion of a comet is said to be "direct" (or +) when it moves in the order of the signs of the zodiac; and "retrograde" (or −) when it moves contrary to the signs of the zodiac.

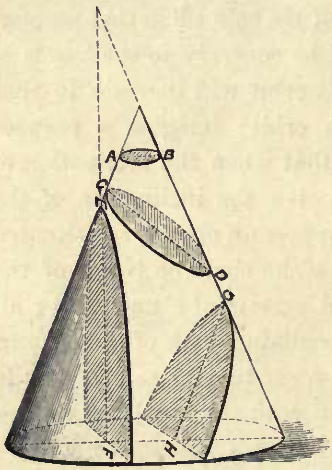
In the case of an elliptic orbit given q and ϵ we can ascertain the length of the major axis (a), and consequently the periodic time.

Given the mean daily motion (μ), we obtain the period in days by dividing 1,296,000 (the number of seconds of arc in a circle) by μ.

Astronomers are accustomed to perform all these calculations by logarithms because of the ease and convenience of doing so.

Be it remembered that the eccentricity is not the linear distance of the centre of the ellipse from either focus, but the ratio of that quantity to the semi-axis major.

Fig. 182.



THE VARIOUS SECTIONS OF A CONE.

Up to the present time the orbits of more than 300 comets have been calculated[h]: a Table of these will be given hereafter.

Fig. 182 represents the various possible sections of a right cone, and will convey a better idea of the orbits of comets than could be given by description. When a right cone is cut at right angles to its axis, the resulting section A B will be a circle; no comet, however, revolves in a circular or even nearly circular orbit. When a cone is cut obliquely, so that the inclination of the cutting plane to the axis of the cone is *greater than* the constant angle formed by the generating line of the cone and the axis, as C D, the resulting section will be an *ellipse*, the shape of which will vary from almost a circle on the one hand to almost a parabola on the other according to the amount of the obliquity.

[h] Gauss's *Theoria Motus Corporum Cœlestium,* 4to. Hamburg, 1809, was long reckoned the standard work on the subject of orbits, but it has in some degree been superseded by Oppolzer's *Lehrbuch zur Bahnbestimmung der Kometen und Planeten,* 2nd ed., 2 vols. 8vo., Leipzic, 1882. A French translation by a Belgian, M. E. Pasquier, was published at Paris, 1886, under the title of *Traité de la détermination des orbites des comètes et des planètes.* See also a paper by Airy, in *Memoirs* R.A.S., vol. xi. p. 181. 1840.

When a cone is cut in a direction, so that the inclination of the cutting plane to the axis of the cone is *less than* the constant angle formed by the generating line of the cone and the axis, as E F, the resulting section will be a *hyperbola*. When a cone is cut in a direction so that the inclination of the cutting plane to the axis of the cone is *equal to* the constant angle formed by the generating line of the cone and the axis, as G H, the resulting section will be a *parabola*.

To the early astronomers the motions of comets gave rise to great embarrassment. Tycho Brahe thought that they moved in circular orbits; Kepler, on the other hand, suggested right lines. Hevelius seems to have been the first to remark that cometary orbits were much curved near the perihelion, the concavity being towards the Sun. He also threw out an idea relative to the parabola, as being the form of a comet's path, though it does not seem to have occurred to him that the Sun was likely to be the focus. Borelli suggested an ellipse or a parabola. Sir William Löwer was probably the first to hint that comets sometimes moved in very eccentric ellipses; this he did in his letter to his "especiall goode friend, Mr. Thomas Harryot," dated Feb. 6, 1610. Dörfel, a native of Upper Saxony, was the first practical man; he showed that the comet of 1680 moved in a parabolic orbit. Sir I. Newton also gave his attention to the subject. Confirming Dörfel, Sir Isaac further showed that the motion of the comet was in accordance with the general Theory of Gravitation.

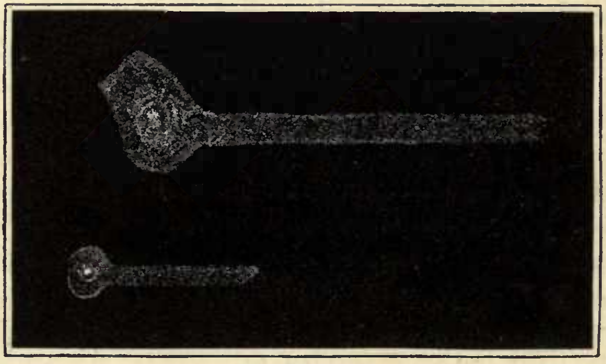
Fig. 183.

THE 1st COMET OF 1847, VISIBLE AT NOON ON MARCH 30. (*Hind.*)

History informs us that some comets have shone with such splendour as to have been distinctly seen in the day-time. The comets of B.C. 43, A.D. 575 (?), 1106, 1402 (i.), 1402 (ii.), 1472, 1532, 1577, 1618 (ii.), 1744, 1843 (i.), 1847 (i.), 1853 (iii.), and 1882 (i.) are the principal ones which have been thus observed.

There are some well-established instances of the separation of a comet into 2 or more distinct portions. Seneca mentions, on the authority of Ephorus, a Greek author, that the comet of 371 B.C. separated into 2 parts which pursued different paths[1]. Seneca seems to distrust the statement he repeats, but Kepler accepted it after what he had himself seen in regard to the great comet of 1618. In the case of this comet Cysatus noticed an evident tendency to break up. When first seen this comet was a nebulous object, but some weeks afterwards it appeared to consist of a group of several small nebulosities. But the best authenticated instance of this character is that of Biela's comet in 1845–6. When first detected, on November 28, it presented the appearance of a faint nebulosity, almost circular, with a slight

Fig. 184.



BIELA'S COMET, FEB. 19, 1846. (*O. Struve.*)

condensation towards the centre: on Dec. 19 it appeared somewhat elongated, and by the end of the month the comet had actually separated into two distinct nebulosities which travelled together for more than 3 months: the maximum distance between the parts (157,240 miles) was attained on March 3, 1846, after which it began to diminish until the comet was lost sight of in April. At its return in 1852 the separation was still maintained, but the interval had increased to 1,250,000 miles. As we shall have to speak of Biela's comet again in a later chapter no more need be said about it here.

[1] *Quæst. Nat.*, lib. vii. cap. 16. But he says however of the writer he quotes:—"Ephorus vero non est religiosissimæ fidei; sæpe decipitur, sæpe decipit."

Biela's comet does not as regards its duplicity stand alone amongst modern comets. A comet seen in February and March 1860, only by M. Liais in Brazil, is said to have consisted of a principal nebulosity accompanied at a short distance by a second nebulosity. It is to be regretted that this object remained visible for so short a time as a fortnight, and that our knowledge of it depends on the authority of but one observer, and he a Frenchman[k]. The 2nd comet of 1881 according to the testimony of 2 observers threw off a fragment which became virtually an independent comet, and lasted as such for some days until all trace of it was lost[l].

The question whether or not comets are self-luminous seems now satisfactorily settled; it cannot be doubted that they are self-luminous, as indeed the spectroscope tells us. The high magnifying power that may sometimes be brought to bear on them tends to show that they shine by their own light. Sir W. Herschel was of this opinion from his observations of the comets of 1807 and 1811 (i.)[m] It is manifest, however, that if the existence of phases could be certainly known, this would furnish an irrefragable proof that the comet exhibiting such shone by reflected light. It has been asserted from time to time that such phases have been seen, but none of the statements ever made seem to deserve attention. Delambre mentions that the registers of the Royal Observatory at Paris exhibit undoubted evidence of the existence of phases in the comet of 1682: but neither Halley nor any other astronomer who observed this comet has given the slightest intimation that any phase-phenomena were visible. James Cassini mentions the existence of phases in the comet of 1744[n]; on the other hand, Heinsius and Chésaux, who paid particular attention to this comet, positively deny having seen anything of the kind. More recently Cacciatore, of Palermo, expressed a decided conviction that he had seen a crescent in the

[k] *Ast. Nach.*, vol. lii. No. 1248. April 14, 1860.

[l] Bone, *Month. Not.*, vol. xlii. p. 105, Jan. 1882: Gould, *Nature*, vol. xxiv. p. 342, Aug. 11, 1881.

[m] *Phil. Trans.*, vol. cii. p. 115. 1812.

[n] *Mém. Acad. des Sciences*, 1744, p. 303.

comet of 1819. Arago sums up the matter by saying that the observations of M. Cacciatore prove only that the nuclei of comets are sometimes very irregular [o]. Sir W. Herschel states that he could see no signs of any phases in the comet of 1807, although he fully ascertained that a portion of its disc was not illuminated by the Sun at the time of observation [p]. The general opinion is against the existence of phases, and thus we must consider that comets shine by their own inherent light; nevertheless the observations of Airy and others on Donati's comet in 1858 point to exactly the opposite conclusion, at least as regards the *tail* of that comet [q], but then the tails of comets are strange ethereal structures, and if we know little about the heads we know less still about the tails. Pons's comet of 1812 was found at its return in 1883 to be brighter than the theory of its orbit led one to expect. Niersten suggested that this fact was a proof that the comet in question was endued with some inherent light of its own.

Some comets have been observed with round and well-defined planetary discs. Seneca relates that one appeared after the death of Demetrius, king of Syria, but little inferior to the Sun [in size?]; being a circle of red fire, sparkling with a light so bright as to surmount the obscurity of night. The comet of 1652, seen by Hevelius, was almost as large as the Moon, though not nearly so bright. The comets of 1665 and 1682 are described as having been as well defined in their outlines as the planet Jupiter. It will be remarked that all these instances were before the days of good telescopes. I am not aware of any modern observations to the same effect.

There are several curious phenomena connected with the tails of comets which require notice. It was observed by Peter Apian that the trains of 5 comets, seen by him between the years 1531 and 1539, were turned *from the Sun*, forming more or less a prolongation of the radius vector, the imaginary line joining the Sun and the comet; as a general rule, this has been found to be

[o] *Pop. Ast.*, vol. i. p. 627, Eng. ed. [p] *Phil. Trans.*, vol. xcviii. p. 156. 1808.
[q] *Green, Obs.*, 1858, p. 90.

the case[r], although exceptions do occur. Thus the tail of the comet of 1577 deviated 21° from the line of the radius vector. Valz has stated that the tails of comets iv. and v. of 1863 deviated from the *planes of the orbits*, and that only 2 other comets are known the tails of which did the same[s]. In some few instances, where a comet has had more than one tail, the 2nd has extended more or less *towards* the Sun; this was the case with the comets of 1823, 1851 (iv.), 1877 (ii.), and 1880 (vii.). Although comets usually have but one tail, yet 2 is by no means an uncommon number; and indeed the great comet of 1825 had 5 tails (Dunlop),

Fig. 185.

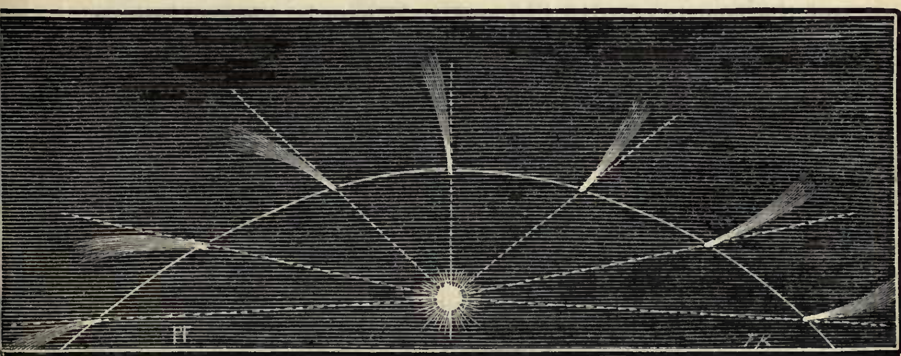


DIAGRAM ILLUSTRATING CHANGES IN THE DIRECTIONS OF THE TAILS OF COMETS.

and that of 1744 as many as 6, or more[t]. The tails of many comets are curved, so as to resemble in appearance a sabre; such was the case with the comets of 1844 (iii.), and 1858 (vi.), amongst others. The comet of 1769 had a double curved tail, thus ~, according to La Nux, who observed it at the Isle of Bourbon. The great comet of 1882 exhibited a striking and uncommon

[r] The researches of M. E. Biot shew that this fact was noticed by the Chinese long before the time of Apian, to wit, in 837. *Comptes Rendus*, vol. xvi. p. 751. 1843.

[s] *Comptes Rendus*, vol. lviii. p. 853. 1864.

[t] This statement long depended on the unconfirmed authority of De Cheseaux, but it is now certain that this comet did exhibit a complete fan of separate tails. (See a paper by Dreyer, with an engraving of the tails, *Copernicus*, vol. iii. 1883.)

form of tail, some account of which will be given in a later chapter.

Occasionally a comet exhibits besides its principal tail a secondary one usually less bright and shorter than the main tail. For instance, Pons's long-period comet of 1812 at its apparition in 1886 had on Dec. 29 a primary tail 8° long and a secondary one very faint and only 3° long. But the secondary tail is not always the shorter of the two. Swift noted a secondary tail in the case of the comet ii. of 1881, which was some 55° long, the longest secondary tail on record [u].

The trains of some great comets have been seen to vibrate in a manner somewhat similar to the Aurora Borealis. The tails of the comets of 1618 (ii.) and 1769 may be cited as instances: the observer in the latter case was Pingré, whose great knowledge of comets adds weight to his testimony. The vibrations commenced at the head, and appeared to traverse the whole length of the comet in a few seconds. It was long supposed that the cause was connected with the nature of the comet itself, but Olbers has pointed out that such appearances could only be fairly attributed to the effects of our own atmosphere, for this reason:—"The various portions of the tail of a large comet must often be situated at widely different distances from the Earth; so that it will frequently happen that the light would require several minutes longer to reach us from the extremity of the tail than from the end near the nucleus. Hence, if the coruscations were caused by some electrical emanation from the head of the comet, even if it occupied but one second in passing over the whole surface, several minutes must necessarily elapse before *we* could see it reach the tail. This is contrary to observation [x], the pulsations being almost instantaneous." Instances of this phenomenon are not very common. The most recent case is that of Coggia's comet of 1874. An English observer at Hereford named With noticed an "oscillatory motion of the fan-shaped jet upon the nucleus as a centre which occurred at intervals of from

[u] *Work of Warner Observatory*, vol. i. p. 22.

[x] *Mém. Acad. des Sciences*, 1775, p. 302.

3 to 8 secs. The fan seemed to 'tilt over' from the preceding to the following side, and then appeared sharply defined and fibrous in structure, then it became nebulous, and all appearance of structure vanished[y]." A flickering of the tail of this comet was observed also by Newall[z].

Respecting the physical constitution of the tails of comets it may be said that probably in many cases they are hollow cones. This theory would accord with the observed fact that single tails usually increase in width towards their extremities and are divided in the middle by a dark band, the brilliancy of the margins exceeding that of the more central portions. Similarly, comets with tails of tolerably uniform width throughout may be regarded as hollow cylinders[a].

The following is an excellent instance of the ever-changing appearance of comets; it relates to that of 1769. On Aug. 8, Messier, whilst exploring with a 2-foot telescope, perceived a round nebulous body, which turned out to be a comet. On the 15th the tail became visible to the naked eye, and appeared to be about 6° in length; on the 28th it measured 15°; on Sept. 2, 36°; on the 6th, 49°; and on the 10th, 60°. The comet having now plunged into the Sun's rays, ceased to be visible. On Oct. 8, the perihelion passage took place; on the 24th of the same month it reappeared, but with a tail only 2° long; on Nov. 1 the tail measured 6°; on the 8th it was only 2½°; on the 30th it was 1½°: the comet then disappeared.

Transits of comets across the Sun no doubt occasionally happen, but only one such spectacle has ever been witnessed, and even then the nature of the sight was not understood till afterwards. The German Sun-spot observer, Pastorff, noticed on June 26, 1819, a round dark nebulous spot on the Sun; it had a bright

[y] *Ast. Reg.*, vol. xiv. p. 13. Jan. 1876.

[z] *Month. Not.*, vol. xxxvi. p. 279. March 1876.

[a] This work is a record of facts rather than of theories, and is too bulky already. Otherwise I might have given it a great expansion by embarking on a review of some of the chief theories which have been broached respecting Comets. For some particulars as to these see a paper by Huggins, *Proc. Roy. Inst.*, vol. x. p. 8, 1882; a paper by Bredichin, *Remarques générales sur les queues des comètes*; also an article by Ranyard in *Ast. Reg.*, vol. xxi. p. 58, March 1883.

point in its centre. Subsequently when the orbit of comet ii., 1819 came to be investigated, Olbers pointed out that the comet must have been projected on the Sun's disc between 5^h and 9^h A.M. Bremen M.T. Pastorff asserted that his "round nebulous spot" was the comet. Olbers, and with him Schumacher, disputed the claim, and the matter seems not free from doubt[b]. Comet v. of 1826 was calculated to cross the Sun on Nov. 18, 1826, but owing to the general prevalence of bad weather in Europe, only 2 observers were fortunate enough to be able to see the Sun on that day, and neither of them could obtain a glimpse of the comet.

Sir J. Herschel once watched Biela's comet pass in front of a cluster of stars, but no obliterating effect was noticed, the several stars being all clearly visible through the comet's ethereal body.

[b] For some further particulars as to this controversy see Webb's *Celest. Obj.*, 4th ed., p. 40, where there is also a facsimile of Pastorff's original sketch. See also an important paper by Hind in *Month. Not.*, vol. xxxvi. p. 309, May 1876. Hind seems to have the idea of there being either error or fraud involved in Pastorff's narrative.

CHAPTER II.

PERIODIC COMETS[a].

Periodic Comets conveniently divided into three classes.—Comets in Class I.—Encke's Comet.—The resisting medium.—Table of periods of revolution.—Tempel's second Comet.—Winnecke's Comet.—Brorsen's Comet.—Tempel's First Comet.—Swift's Comet.—Barnard's Comet.—D'Arrest's Comet.—Finlay's Comet.—Wolf's Comet.—Faye's Comet.—Denning's Comet.—Mechain's Comet of 1790.*—Now known as Tuttle's Comet.—Biela's Comet.—Di Vico's Comet of* 1844.*—List of Comets presumed to be of short periods but only once observed.—Comets in Class II.—Westphal's Comet.—Pons's Comet of* 1812.*—Di Vico's Comet of* 1846.*—Olbers's Comet of* 1815.*—Brorsen's Comet of* 1847.*—Halley's Comet.—Of special interest.—Résumé of Halley's labours.—Its return in* 1759.*—Its return in* 1835.*—Its history prior to* 1531 *traced by Hind.—Comets in Class III not requiring detailed notice.*

THE comets which I propose to treat of in the present chapter may be conveniently divided into 3 classes:—

1. Comets of short periods.
2. Comets revolving in about 70 years.
3. Comets of long periods.

The following are the comets belonging to Class I, with which we are best acquainted:—

Name.	Period.	Next Return.
	Years.	
1. Encke's	3·29	1891 Oct.
2. Tempel's Second (1873, ii.)	5·15	1894 Feb.
3. Winnecke's	5·54	1891 Dec.
4. Brorsen's	5·58	1890 April
5. Tempel's First (1867, ii.)	5·98	1891 April
6. Swift's (1880, v.)	6·00	1892 Oct.
7. Barnard's (1884, ii.)	±6	1890
8. D'Arrest's	6·64	1890 Sept.
9. Finlay's	6·67	1893
10. Wolf's (1884, iii.)	6·76	1891 Aug.
11. Faye's	7·44	1895 Dec.
12. Denning's	8·86	1890 July
13. Tuttle's...	13·66	1899 March

[a] If it should be suggested that I have given too much space here to the Periodic Comets, I would answer by way of excuse that they are, historically

Encke's Comet.

No. 1 is by far the most interesting comet in the list, and I shall therefore review its history somewhat in detail.

On Jan. 17, 1786, Méchain, at Paris, discovered a small telescopic comet near the star β in the constellation Aquarius. On the following day he announced his discovery to Messier, who, owing to unfavourable weather, did not see it till the 19th, on which night it was also observed by J. D. Cassini, Jun., and the original discoverer. It was tolerably large and well-defined, and had a bright nucleus, but no tail.

On Nov. 7, 1795, Miss Caroline Herschel, sister of Sir W. Herschel, discovered a small comet, about 5′ in diameter, without a nucleus, but yet having a slight central condensation of light. Olbers observed it on Nov. 21, when it was too faint to allow of the field being illuminated, and he was obliged to compare it with stars in the same parallel by noting the times of transit across the field of view. It was round, badly defined, and about 3′ in diameter. The orbit greatly perplexed the calculator, and Prosperin declared that no parabola would satisfy the observations.

On Oct. 19, 1805, Thulis, at Marseilles, discovered a small comet, which was faintly visible to the naked eye. Huth stated that on the 20th it was very bright in the centre, though without a nucleus, and 4′ or 5′ in diameter. On Nov. 1 the same observer saw a tail 3° long. Several parabolic orbits were calculated, and one elliptic one by Encke, to which a period of 12·127 years was assigned.

On Nov. 26, 1818, the indefatigable Pons, of Marseilles, discovered a telescopic comet in Pegasus, which was very small and ill-defined. As it remained visible for nearly 7 weeks, or till Jan. 12, 1819, a rather long series of observations was obtained; and Encke, finding that under no circumstances whatever would

and physically, very interesting objects; that scarcely a year ever passes that some of them do not return to the Sun and therefore to visibility as regards the Earth; and that, consequently, they are objects which furnish many instructive chances to the class of students for whom this work is mainly intended.

a parabolic orbit fairly represent them, determined rigorously to investigate the elements according to the method of Gauss, then but little practised. Having done this, he found that the true form of the orbit was elliptical, and that it had a period of about 3½ years. On looking over a catalogue of all the comets then known, he was struck with the similarity which the elements obtained by him bore to those of the comets of 1786 (i.), 1795, and 1805, and he was strongly impressed with the idea that the comet whose movements were then under investigation was identical with those comets, more particularly as, on the assumption of a 3⅓-year period, it might be expected to have been in perihelion at about those epochs. This question could only be settled by calculating backwards the effects of planetary perturbation, which Encke by an extraordinary effort did in 6 weeks. He was accordingly able to assure himself of the identity of the comet of 1818 with the 3 above-mentioned ones, and also that between 1786 and 1818 it had passed through perihelion 7 times without being seen.

Encke then proceeded to calculate its next return, and he announced that the comet would arrive at perihelion on May 24, 1822, after being retarded about 9 days by the influence of the planet Jupiter.

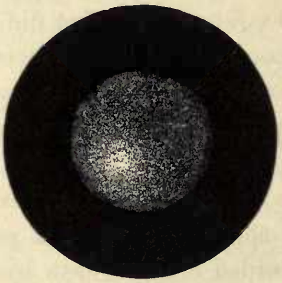
"So completely were these calculations fulfilled, that astronomers universally attached the name of 'Encke' to the comet of 1819, not only as an acknowledgment of his diligence and success in the performance of some of the most intricate and laborious computations that occur in practical astronomy, but also to mark the epoch of the first detection of a comet of short period—one of no ordinary importance in this department of science."

It unfortunately happened that at its return in 1822 the position of the comet in the heavens was such as to render it invisible in the Northern hemisphere. It was therefore systematically watched by only one observer, M. Rümker, who discovered it on June 2, at the private observatory of Sir T. M. Brisbane, at Paramatta, New South Wales, and he was able to follow it for only 3 weeks. Rümker's observations were, however, so far valuable, that besides showing that the comet actually did come back, they furnished Encke with the means of predicting with greater certainty its next return, which he found would occur on Sept. 16, 1825.

On this occasion it was first seen by Valz, on July 13, but was discovered independently by more than one other astronomer. Cacciatore, of Palermo, described it as being round, with a faint nebulosity, and about 1° 30′ in diameter.

The next return to perihelion took place on Jan. 9, 1829. Struve, at Dorpat, found it on Oct. 13, 1828: Harding, at Göttingen, and Gambart, at Marseilles, both saw it for the first

Fig. 186.



ENCKE'S COMET: NOV. 30, 1828. (*W. Struve.*)

time on the same day, Oct. 27, the former having been on the look-out since Aug. 19, and it was very generally observed till the end of December in the same year. On Nov. 30 it was visible to the naked eye as a star of the 6th magnitude, and a week afterwards it had become as bright as a star of the 5th magnitude. The outline of the coma was slightly oval, with the minor axis (on one occasion at least) pointing towards the Sun.

The 4th of May, 1832, was calculated as the epoch of the next perihelion passage. The comet was discovered by Mossotti, at Buenos Ayres, on June 1, and by Henderson, at the Cape of Good Hope, on the following night. Harding, at Göttingen, who saw it on Aug. 21, was the only European observer who caught a glimpse of it, owing to its path lying chiefly in the Southern heavens.

The next return to perihelion was fixed for Aug. 26, 1835. The comet was seen both in Europe and at the Cape of Good Hope.

Dec. 9, 1838, was the epoch of the next perihelion passage; and as the comet's apparent path would be such as to allow observations to be made in Europe under very favourable conditions, it was looked for with much interest. Boguslawski discovered it on Aug. 14; but Galle, at Berlin, did not see it till Sept. 16; and it was not generally seen till the middle of October. At about the end of the first week in November it was visible to the naked eye in Draco; with a telescope a rather bright nucleus was seen, and the general form of the coma was that of a broad parabola.

The account of this return would be incomplete were I not to refer to a peculiarity connected with the comet's motion, which, though it attracted Encke's attention as far back as 1818, may be said not to have been brought into special prominence till the return of 1838. He found that, notwithstanding every allowance being made for planetary influences, the comet always attained its perihelion distance about 2½ hours sooner than his calculations led him to expect. In order to account for this gradual diminution of the period of revolution, which in 1789 was nearly 1213^{d}, but in 1838 was scarcely $1211\frac{1}{10}^{d}$, Encke conjectured the existence of a thin ethereal medium, sufficiently dense to produce an effect on a body of such extreme tenuity as the comet in question, but incapable of exercising any sensible influence on the movements of the planets. "This contraction of the orbit must be continually progressing, if we suppose the existence of such a medium; and we are naturally led to inquire, What will be the final consequence of this resistance? Though the catastrophe may be averted for many ages by the powerful attraction of the larger planets, especially Jupiter, will not the comet be at last precipitated on the Sun? The question is full of interest, though altogether open to conjecture."

The following table, published by Encke[b], will more clearly illustrate the changes in the comet's periodic time:—

Year of PP.	Period, Days.
1786	
(1789)	1212·79
(1792)	1212·67
1795	1212·55
(1799)	1212·44
(1802)	1212·33
1805	1212·22
(1809)	1212·10
(1812)	1212·00
(1815)	1211·89
1819	1211·78
1822	1211·66
1825	1211·55
1829	1211·44
1832	1211·32
1835	1211·22
1838	1211·11
1842	1210·98
1845	1210·88
1848	1210·77
1852	1210·65
1855	1210·55
1858	1210·44

The propriety of this explanation of a resisting medium has been warmly canvassed at different times, and it cannot be said yet to command universal assent. One strong point against it is, that, with the exception *perhaps* of Winnecke's, none of the other short-period comets (all of them of small size and, presumably, unimportant mass) yield any indications that they experience a like influence[c]. On the other hand, Von Asten, who worked at the problem with great perseverance, thought there ought to be no hesitation in accepting the idea, subject to the limitation that the medium does not extend beyond the orbit of Mercury.

The 1838 return is also noticeable for an important discovery in physical astronomy which it, indirectly, was the cause of evolving. In Aug. 1835 the comet passed very near the planet Mercury—so near, in fact, that Encke showed that if Laplace's value of Mercury's mass were correct, the planet's attractive power would diminish the comet's geocentric R.A. on Nov. 2, 1838, by 58′, and increase its Declination by 17′. As the observations indicated no such disturbance of the comet's orbit, it was obvious that the received mass of the planet was far too great, and a much lower value has since been adopted[d].

[b] *Month. Not.*, vol. xix. p. 70. Dec. 1858.

[c] See a notice of a paper by A. Hall in *Month. Not.*, vol. xxxiii. p. 239. Feb. 1873.

[d] In Hind's *Comets*, p. 65 *et seq.*, the

Passing over the returns of 1842 and 1845, as offering no features of particular interest, we find that in 1848, on Sept. 24, the diameter of the comet's head was 8′, and that it was just visible to the naked eye on Oct. 6, and for some weeks subsequently. Early in November it had a tail about 1° long, turned *from* the Sun, and another and smaller one directed *towards* that luminary. On Nov. 22, at midnight, the comet was distant but 3,600,000 miles from Mercury. The frontispiece to this volume will convey a good idea of the appearance of the comet at this apparition.

Passing over also the returns of 1852, 1855, and 1858, we arrive at that of 1862, the 17th on record. The passage through the perihelion took place on Feb. 6, but the comet was discovered by Förster, at Berlin, as early as Sept. 28, 1861. It was then very faint, and difficult of observation. The same character applies to the return of 1865, which was observed only in the Southern hemisphere. In 1868 the comet was unfavourably placed and was seen by only a few observers.

In 1871, on the other hand, the comet was well seen and numerous observations of it were made. For a day or two in November, it was within the reach of telescopes of small dimensions. Some physical peculiarities were noted at this apparition which deserve mention. When first discovered in August, the comet was a nearly round and faint nebulosity, without apparent condensation in any part. By the beginning of November, it had acquired a remarkable fan-like form, but the precise character of the exterior outline differed a good deal according to the power of the telescope employed.

Mr. Carpenter said[e]:—

"I was able to make out a considerable extension of the illumination beyond the bright fan-shaped condensation, but on one side (the spreading side) only. On the opposite side this diffused illumination appeared to be cut off nearly in a straight line immediately behind (following) the apex of the fan."

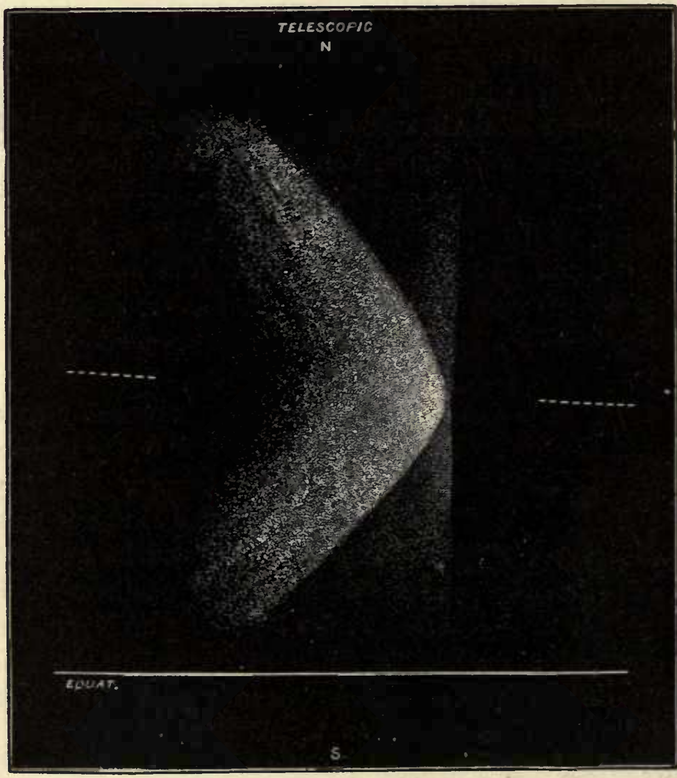
general principles upon which these inquiries are conducted are laid down with that clearness of language for which that astronomer is noted in the treatment of difficult matters.

[e] *Month. Not.*, vol. xxxii. p. 26. Nov. 1871.

The Rev. H. C. Key, speaking in the first instance of what he saw on December 3, said[f]:—

"The train following the comet was quite broad in my telescope, and could not be termed a 'ray.' You will observe two rays on the preceding side; these I have drawn as you see, but I am not perfectly certain that the effect was not in my own eye and not a reality. I took every precaution to find out; and at the time (as well

Fig. 187.



ENCKE'S COMET: NOV. 9, 1871. (*J. Carpenter.*)

as now) felt pretty well convinced that it was no illusion. Four or five times I left the telescope, and upon returning there were the rays in exactly the same spot and direction. I feel pretty confident of their reality (they were extremely faint), but, as I say, am not quite certain, as I sometimes see dark lines in the field when first going to the telescope. The comet never seemed to me to lose its elliptical form from the first night I saw it, Oct. 20th. I detected a nucleus for the first time on

[f] *Month. Not.*, vol. xxxii. p. 217. March 1872.

Nov. 7th. The train I mentioned before was much fainter than the main body of the comet, and I was able to trace it to a distance of about 32′ from the nucleus. I saw nothing like the drawing of the comet made at Greenwich."

The return of 1871 was also important by reason of the fact that it was found not to have been accelerated, in accordance with the Resisting Medium theory, as all previous returns had been. Von Asten's conjecture as to this is that in 1869 the comet might have come into collision with some unknown minor planet which violently deranged its orbit and modified the orbit in some degree[g].

Encke's comet returned to perihelion again in April 1875, but no observations were made calling for notice.

In 1878 the comet was best seen in the Southern hemisphere. Its diameter on August 10 was about 2′, and it resembled generally a star of the 8th magnitude, according to the account given by Gould. In the Northern hemisphere it was observed with extreme difficulty by Winnecke at Strasburg on Aug. 20 and by Tempel at Arcetri on Aug. 21. O. Struve, even with the great 15-inch refractor at his command, did not catch sight of it till Aug. 24.

In 1881 the comet passed through perihelion on Nov. 18. It was noted by Common, using a 3-ft. reflector, as about 2′ in diameter, very faint, and with slight indications of an increased brightness in the centre. Tacchini found the spectrum to exhibie bright bands in the yellow, green, and blue respectively, coinciding with the 3 principal bands seen in the spectra of the hydro-carbons. As in some other comets, the bands were shaded off to the blue. A faint continuous spectrum was also detected[h]. The spectrum was considered to have undergone no change since the previous examination in 1878.

In 1884 the comet was observed by Tempel on Dec. 13, but it was extremely faint. In 1888 it was seen only in the Southern hemisphere, being first detected by Tebbutt at Windsor, N.S.W., on July 8, about 10 days after passing perihelion.

[g] *Bulletin de l'Acad. de St. Petersbourg,* vol. v. *Observatory,* vol. i. p. 21. April 1877.
[h] *Comptes Rendus,* vol. xciii. p. 947.

M. Berberich has written an interesting historial paper on the brightness of Encke's comet at its many successive apparitions[1].

Tempel's Second Periodical Comet.

No. 2.—On July 3, 1873, Tempel at Milan discovered a small faint comet. It was described as being somewhat elongated, with an eccentric condensation, and a granular appearance. The diameter was at least 2′. It quickly became evident that the comet moved in an elliptic orbit of short period. Hind pointed out that soon after passing its ascending node and when near aphelion the comet passes close to the orbit of Jupiter, in which fact is to be found the cause of its periodicity.

This comet returned again to perihelion in August 1878. It was seen at Oxford with difficulty in the 12-inch refractor of the University Observatory, and resembled a faint round nebula 1′ in diameter, with a very slight central condensation.

At the return of 1883 (PP. on Nov. 20) the comet was not seen owing to its unfavourable position.

Winnecke's Comet,

No. 3, was discovered by M. Pons, on June 12, 1819. Encke assigned to it a period of 5½ years, which, as the table will show, was a very close approximation to the truth. It was not, however, seen from that time till March 8, 1858, when it was detected by Winnecke, at Bonn, and by him regarded as a new comet; but he soon ascertained the identity of the two objects. It must have returned in 1863, but was not on that occasion favourably placed for observation. The next return to perihelion occurred in June 1869. The comet was viewed by Winnecke himself on April 9 of that year, and is described by him as being faint, but not less than 6′ or 8′ in diameter. Winnecke's comet was again visible in 1875 passing through perihelion on March 11.

Some calculations by Oppolzer led him to think that this comet was observed previous to the occasion which has

[1] *Ast. Nach.*, vol. cxix., No. 2836, Ap. 24, 1888.

usually been considered its first discovery (namely its detection by Pons in 1819), and that it is identical with the comet discovered by Pons in Feb. 1808. (See the Catalogue of "Uncalculated" Comets, *post*, p. 585.)

It was due again in the Autumn of 1880, but escaped notice. In 1886 however it was seen in the Southern hemisphere after perihelion passage. It passed its perihelion 12 days earlier than it was predicted to do, and according to Oppolzer its movements cannot be completely explained by the theory of gravitation alone, but the existence of some resisting medium seems indicated.

BRORSEN'S COMET,

No. 4, was detected by M. Brorsen, at Kiel, on Feb. 26, 1846. The observations showed an elliptic orbit, and the epoch of the ensuing arrival at perihelion was fixed for Sept. 26, 1851, but its position then was not very favourable, owing to its proximity to the Sun, and it escaped observation. Bruhns again discovered it on March 18, 1857. I saw it on March 23; it possessed the usual nebulous appearance common to these objects, and had a diameter of about 2′, though it was unfavourably placed in the morning twilight, which probably marred its brilliancy. This comet again returned to perihelion in April 1868, Oct. 1873, and March 1879. Spectroscopic observations on the last-named occasion by Konkoly in Hungary and C. A. Young in America tended to show that the spectra of this and of Encke's comet were identical with one another, and with a hydro-carbon spectrum[j]. Brorsen's comet escaped notice at its return in Sept. 1884.

The period of Brorsen's comet has been gradually diminishing owing to the effect of planetary perturbation. Thus:—

In 1846;	period	= 2034	days.
„ 1857;	„	= 2022	„
„ 1868;	„	= 2002	„
„ 1873;	„	= 1999	„
„ 1879;	„	= 1994	„

[j] *Observatory*, vol. iii. pp. 56, 105, June, August, 1879.

It was missed, as stated above, at the returns of 1851 and 1862 owing to its unfavourable position. The present orbit was due to the action of Jupiter in 1842, and, according to D'Arrest, serious disturbances from the same cause will happen in 1937 [k].

Tempel's First Periodical Comet.

No. 5.—On April 3, 1867, Tempel at Milan discovered a small telescopic comet. It had a nucleus which was eccentrically placed in an oval coma, and Talmage, on May 3, thought that the nucleus appeared to have a division across the centre. The comet remained visible for about 4 months, which time sufficed to make it evident that its orbit was an ellipse of short period. Searle's value of the period was 2064 days; Bruhns's slightly greater, 2074 days.

On July 3, 1873, Tempel discovered a comet which in his telegram he described as "schwach" (faint). Several computers obtained elliptic elements of its orbit, but, strangely enough, some time elapsed before the comet's identity with comet ii. of 1867 was found out. It returned to perihelion in May 1879, and is now recognised as a permanent addition to the List of Short-period Comets. But it escaped detection at its return in the Spring of 1885.

Swift's Comet.

No. 6.—On Oct. 10, 1880, Prof. Swift at Rochester, New Jersey, U.S., found a small comet with a very diffused and ill-defined disc several minutes in diameter. It was soon ascertained by Chandler that the orbit was elliptic with a period of 6 years, and the comet identical with comet iii. 1869, discovered by Tempel on Nov. 27 of that year. The comet had been very unfavourably circumstanced for observation at the return of 1874, and had escaped detection. It was also unfavourably placed at its return in 1886. It is a peculiarity of this comet that it is well situated for observation only at alternate returns to perihelion.

[k] *Nature*, vol. xxx. p. 301, July 24, 1884.

BARNARD'S COMET.

No. 7.—On July 16, 1884, Mr. E. E. Barnard, at Nashville, Tennessee, U.S., using a 6-inch refractor, discovered a nebulous object which he thought had a suspicious appearance. Some days however elapsed ere it was found to be in motion and its cometary character ascertained beyond a doubt. Perrotin described the comet as exhibiting on Aug. 15 an ill-defined nebulosity about $1\frac{1}{2}'$ in diameter, and having a granular structure towards its centre. There is no doubt that the orbit is elliptical; the period is at present somewhat uncertain; but it is probably about 6 years. If Berberich's period of 5·49 years is correct, the comet must have approached very near indeed to Mars between April 5 and 10, 1868, and have had its orbit perturbed by that planet.

D'ARREST'S COMET.

No. 8.—On June 27, 1851, D'Arrest, at Leipzig, discovered a very faint telescopic comet in the constellation Pisces. Within a fortnight of its discovery the observations appeared irreconcileable with a parabolic orbit, and it was soon placed beyond a doubt that its true path was an ellipse. The comet was visible for more than 3 months; but notwithstanding this, the results of the calculations of the orbit were very discordant, and the predicted return of the comet in the winter of 1857–8 must be regarded rather in the light of a successful guess than anything else. Sir T. Maclear, at the Royal Observatory, Cape of Good Hope, was the only observer of this apparition.

M. Villarceau communicated to the Academy of Sciences at Paris, on July 22, 1861, an interesting memoir on the orbit of this comet, which may be usefully placed on record (in an epitomised form) as it will serve to give some insight into the nature of the mathematical investigations which the calculators of cometary orbits are called upon to conduct:—

The perturbations experienced by this comet are owing chiefly to the action of Jupiter, to which it is so near, that during the month of April of the present year [1861] its distance was only 0·36, or little more than *one-third* of the Earth's distance from the Sun. Before and after this epoch, Jupiter and the comet have continued, and will continue, so little distant from one another, as to produce the great perturbations to which the comet is at present subject.

From a table of the elements of the perturbations produced by Jupiter, Saturn, and Mars, in the interval between the appearance of the comet in 1857–8 and its return to its perihelion in 1864, M. Villarceau obtained the following results:—

(1) The longitude of the perihelion will have diminished 4° 35′ to Aug. 1863, and will remain sensibly stationary for about a year from that epoch. (2) The longitude of the node will have continually diminished to the amount of 2° 8′. (3) The inclination will have increased 1° 49′ to the middle of 1862, and will diminish 6′ during a year, continuing stationary during the year following. (4) The eccentricity, after having increased to the middle of 1860, will diminish rather quickly, and will remain stationary from 1863–5 to 1864–6. "But of all these perturbations," says M. Villarceau, "the most considerable are those of the mean motion and the mean anomaly. After having increased from 5″ to July, 1860 the mean motion diminishes 9″ in one year, and nearly 12″ in the year following, remaining stationary in the last year, and with a value 15″, 5″ less than at its origin. The perturbations of the mean anomaly, after having gradually increased till 1860, will increase rapidly till 1861, when they will amount to 10° 28′; and setting out from this, they will increase 9′, and in 1863 and 1864 they will have resumed the same value which they had in 1861."

The effect of the first of these perturbations will be to increase the time of the comet's revolution by about 69 days; and of the second, to hasten by 49 days the return of the comet to its perihelion in 1864. It will pass its perihelion on Feb. 26, whereas without the influence of these perturbations it would have passed it on April 15.

As was anticipated, the comet escaped notice altogether at its return to perihelion in 1864. But in 1870, astronomers were more fortunate, and were able to follow it for 4 months. Winnecke has pointed out that D'Arrest's comet is undoubtedly the faintest of all the known periodic comets[1]. It came back again to perihelion in 1877, but was not seen at its return in the winter of 1883.

Finlay's Comet,

No. 9.—On Sept. 26, 1886, a small tailless comet 1′ in diameter was discovered at the Royal Observatory, Cape of Good Hope. It was at first thought to be possibly identical with the lost comet of Di Vico, but subsequent investigation negatived this theory: it is however certainly a short-period comet, and its next return will be looked forward to with interest.

[1] *Ast. Nach.*, vol. lxxv. No. 1824, Oct. 12, 1870.

WOLF'S COMET.

No. 10.—On Sept. 17, 1884, Dr. Wolf of Heidelberg discovered a small telescopic comet which Col. Tupman described a week later as about 2′ in diameter and possessing a stellar nucleus 3″ in diameter. It soon proved to be a short-period comet revolving round the Sun in about $6\frac{1}{2}$ years.

FAYE'S COMET,

No. 11, was discovered by M. Faye, at the Paris Observatory, on Nov. 22, 1843, it being then in the constellation Orion. It exhibited a bright nucleus, with a short tail, but was never sufficiently brilliant to be seen by the unaided eye. That the comet's path was an ellipse seems to have been suspected independently by more than one observer. To Le Verrier, however, is due the credit of having completely investigated its elements. That astronomer showed that the comet came into our system at least as far back as the year 1747, when it suffered much perturbation from Jupiter[m]; and, further, that its next perihelion passage would occur on April 3, 1851.

It was rediscovered by Challis, at Cambridge, on Nov. 28, 1850. O. Struve described it, under the date of Jan. 24, 1851, as having a diameter of 24″. During the whole time it was observed it had scarcely any nucleus or tail. This comet returned in due course to perihelion on Sept. 12, 1858, having been detected 4 days previously by Bruhns, at Berlin. It was also seen in 1866, 1873, 1880[n], and 1888, and next after Halley's and Encke's comets may

[m] The intelligent reader may wonder why Jupiter is so constantly called to account as the great bugbear of these short-period comets. The reasons are two in number:—(1) The immense *mass* of Jupiter compared with that of any of the other planets; and (2) the fact that the aphelia of all these comets lie very close to the orbit of Jupiter; so that when at their greatest distance from the Sun, they are constantly liable to *rencontres* more or less intimate, though by no means friendly, with the colossal planet. It is, moreover, an incidental indication of the potency of Jupiter's influence over comets, that so many short-period comets have periods amounting to between 5 and 6 years, being about the time occupied by Jupiter in traversing *half* its orbit. (See Fig. 181, on p. 402, *ante*.)

[n] For a fuller history of this comet see *Month. Not.*, vol. xli. p. 246, Feb. 1881.

be regarded as the best-known cometary member of the Solar system.

Denning's Comet.

No. 12.—On Oct. 4, 1881, Mr. W. F. Denning at Bristol discovered a bright telescopic comet in the constellation Leo. It was circular in form, about 1′ in diameter, and showed a slight central condensation. The ellipticity of its orbit soon became known to those who undertook the computation of its elements, and there is no doubt that it constitutes an interesting addition to our list of short-period comets, and the first made by an Englishman.

The elements bear some resemblance to those of the comet of 1819 (iv.), discovered by Blainpain. Winnecke thinks that the comet seen at Paris in 1855 by Goldschmidt, and then regarded as perhaps Di Vico's, and Hind's comet of 1846 (ix.), may both have been apparitions of Denning's comet. The further consideration of these suggestions must stand over till after the next return of this object to perihelion, which will be awaited with much interest by astronomers, the more so as it is known that it must come much under the influence of several of the major planets.

Tuttle's Comet,

No. 13, was detected by Méchain, on Jan. 9, 1790. It was only followed for a fortnight. On Jan. 11 Messier could see but a confused nebulosity, without any indications of a nucleus. It was not re-observed until its return at the commencement of 1858, on Jan. 4 of which year it was detected by H. P. Tuttle, at Harvard College Observatory, Cambridge, U.S. It returned again to perihelion in Nov. 1871 and Aug. 1885, and is now accepted as a regular member of the group of short-period comets. On the last occasion it was very faint, and was only followed in the morning twilight for about a fortnight.

Biela's Comet.

Besides those enumerated in the Table, there is another very remarkable periodic comet, even more interesting than Encke's, but for altogether a different reason: I shall therefore give its history at some length.

On March 8, 1772, Montaigne, at Limoges, discovered a comet in Eridanus, which, from want of suitable instruments, he was unable properly to observe, or to see at all after the 20th; Messier, however, saw it four times between March 26 and April 3.

On Nov. 10, 1805, Pons discovered a comet, which was found also by Bouvard on the 16th. It had a nucleus, and the diameter of the coma on Nov. 23 was 6′ or 7′. On Dec. 8 it was at its nearest point to the Earth, and Olbers saw it without a telescope. Bessel and others calculated elliptic elements, and its identity with the comet of 1772 was suspected, though no predictions as to its next return were ventured on.

On Feb. 27, 1826, M. Biela, at Josephstadt, Bohemia, discovered a faint comet in Aries, which Gambart found on March 9. The observations extended altogether over a period of 8 weeks, and it was soon made evident that the orbit was an ellipse of moderate eccentricity; and further, that the comet was the same as that which had already been observed in 1772 and 1805.

In anticipation of its next return in 1832 investigations into the orbit of the comet and the perturbations by which it would be affected were undertaken by Santini, Damoiseau, and Olbers. Santini found that its period in 1826 was 2455 days, but that the attraction of the Earth, Jupiter, and Saturn would accelerate its next return by rather more than 10 days, which he accordingly fixed for Nov. 27, 1832. Damoiseau's investigations gave a similar result. Early in 1828 Olbers called attention to the fact that in 1832 the comet would pass within 20,000 miles of the Earth's *orbit;* but that as the Earth would not reach that particular point till one month after the comet had passed it, no danger was to be apprehended. Astronomers were quite satisfied as regards this matter, but their confidence was not shared by the unscientific many, who were greatly alarmed lest a collision should take place, and our globe become a sufferer thereby.

Punctually at the time appointed the comet returned to perihelion, through which it passed within 12 *hours* of the time fixed by Santini five years previously. It was first seen at Rome on Aug. 23, but, owing to its excessive faintness, it was not generally observed till two months later.

The next return was calculated to take place on July 23, 1839, but in consequence of its close proximity to the Sun, the comet was not detected.

Continuing his researches, Santini fixed on Feb. 11, 1846, as the epoch of the next perihelion passage; and as it would be visible for a considerable period, much interest was excited amongst astronomers, who anticipated that a remarkably good opportunity would be afforded for correcting the theory of its motion.

Di Vico, at Rome, with the powerful telescope at his command, discovered it on Nov. 28, 1845, and Galle, at Berlin, saw it two days later; but by the generality of observers it was not seen till the second or third week in December. I have already adverted to the very curious phenomenon which took place at this apparition of Biela's comet. (See *ante*, p. 408.)

The comet returned again to perihelion in Sept. 1852, and was visible for three weeks. The same reason which prevented it from being seen in 1839 also caused it to pass undetected in May 1859; so that we were obliged to await its next return to perihelion in Jan. 1866 for further information relative to its physical condition. This return was looked forward to with much interest; as it was important to know what changes had occurred during the preceding 13 years in the relative position of the two portions so strangely rent asunder, as already narrated —whether they still travelled through space in company or not. That between 1846 and 1852 they had become, for all practical purposes, two complete comets, seemed indisputable; and in the sweeping Ephemerides issued from the *Nautical Almanac* office, by Mr. Hind, for facilitating their rediscovery in 1859, two independent sets of elements and positions were given.

It was calculated that the comet would have been seen in

1865–6 under very favourable circumstances, and search was systematically made for it at numerous European Observatories, but without success. Much disappointment was felt by astronomers: and startling as such a suggestion may appear [o], even the continued *existence* of the comet seemed so open to uncertainty that all hopes of seeing it again were given up. At least one man, however, did not despair. M. Klinkerfues of Göttingen kept the subject before him, and as the result of his labours, he sent, on Nov. 30, 1872, to Pogson at Madras, a telegram as follows: "*Biela touched Earth on 27th: search near θ Centauri.*" The search was made, and *a* comet found, and observations of it were obtained on Dec. 2 and 3, 1872. Bad weather and the advance of twilight prevented further success [p]. Here the matter rests: it was however the opinion of Bruhns that the comet seen by Pogson could not possibly have been Biela's, but was, by a remarkable coincidence, some other.

The further consideration of the question "Why has Biela's comet disappeared?" seems now to belong to the subject not of Cometic but of Meteoric Astronomy. Accordingly we shall have more to say about it in Book V (*post*).

DI VICO'S COMET.

On Aug. 22, 1844, M. Di Vico, at Rome, discovered a telescopic comet, which, towards the end of the following month, became perceptible to the naked eye. With a telescope a bright stellar nucleus and a short tail were seen. It some became evident that the observations could not be reconciled with any parabolic orbit, and elliptic elements were calculated by several computers. The most complete investigation is due to Brünnow, who found that the comet's periodic time was 1993 days. Carrying on his researches to the next return to perihelion, which was calculated

[o] I assume that we are required to ignore certain alleged observations of "something" which formed a topic of discussion at several meetings of the Royal Astronomical Society, in the spring of 1866. (See *Month. Not.*, vol. xxvi. pp. 241 and 271.)

[p] *Month. Not.*, vol. xxxiii. p. 116. Dec. 1872.

to occur in the spring of 1850, he found that "when the comet was near enough to the Earth to be otherwise discerned, it was always lost in the Sun's rays, the geocentric positions of the Sun and comet at perihelion being nearly the same, and continuing so for some months, on account of the apparent direct movement of both bodies."

Its next return to perihelion was fixed for Aug. 6, 1855; and as it would be favourably situated for observation, hopes were entertained that it would again be detected. Such, however, was not the case; nor was it seen in 1861, 1866, 1872, or 1877 and therefore we are no longer justified in including it in the list of "known" short-period comets, but its size and brilliancy (considerable for a short-period comet) render its non-appearance since 1844 a remarkable fact. Certain computations by Le Verrier render it probable that this comet is identical with that of 1678.

On Sept. 26, 1886, Finlay discovered a small comet the elements of whose orbit were found to resemble closely those assigned to Di Vico's comet by Brünnow; but the resemblance appears to be fortuitous: that is to say, that they are 2 distinct comets moving in orbits similar in many respects but not in all.

Another instance of this sort of thing seems to be exhibited by the comets of 1843 (i.), 1880 (i.), and 1882 (ii.).

Short periods have also been assigned to the following comets; but too much uncertainty prevails with respect to them, to justify their being included with the foregoing [q]:—

Clausen (1743, i.)	Blainpain (1819, iv.)
Burckhardt (1766, ii.)	Peters (1846, vi.
Lexell (1770, i.)	Coggia (1873, vii.).
Pigott (1783)	

The last-named of these comets (1873, vii.) was the subject of an elaborate investigation by Weiss, who thought it a return of the comet of 1818 (i.), but he could not satisfy himself whether

[q] The reader will find a few brief particulars in the notes to the 1st catalogue (*post*); but for further information he must consult Hind's *Comets*, or Cooper's *Cometic Orbits*—two works which everybody interested in this branch of astronomy ought to possess. Those who read German will find P. Carl's *Repertorium der Cometen-Astronomie*, published at Munich in 1864, a useful book.

its period was 55·8, 18·6, or 6·2 years, though he gives the preference to 6·2 years.

In Class II. we have the following comets :—

Name.	Period.	Probable next Return.
	Years.	
1. Westphal (1852, iv.)	67·77	1920
2. Pons (1812)	70·68	1954
3. Di Vico (1846, iv.)	73·25	1919
4. Olbers (1815)	74·05	1961
5. Brorsen (1847, v.)	74·97	1922
6. Halley	76·78	1910

It has been suggested (I know not by whom) that 4 of the above may have originally constituted a single comet. Independently of this, Kirkwood has given reasons why some connection may exist between Nos. 2 and 3 in the above Table.

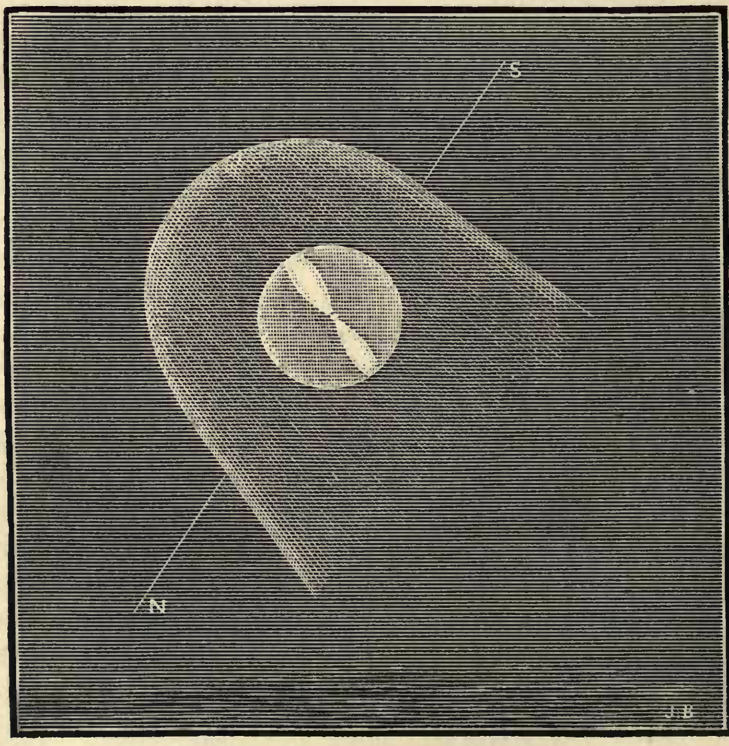
No. 2 was discovered by the indefatigable Pons on July 20, 1812, being the 16th comet found by him in 10 years. It had an irregular nebulous form without tail or beard, and was only visible through a telescope. Encke having assigned a period of 70·7 years, the return of the comet was anticipated about 1883, and accordingly it was sighted on Sept. 3 by Brooks in America by the aid of a sweeping ephemeris computed by Schulhof and Bossert. It appears to have exhibited in 1883–4 physical characteristics differing altogether from anything recorded in 1812. Chandler in America and Schiaparelli in Italy saw it on several occasions in Sept. 1883, first as a nebulosity, then as a star, then as a nebulosity again; whilst Müller at Potsdam on Jan. 1, 1884 observed changes up and down both in magnitude and brightness to the extent of $\frac{7}{10}$ of a magnitude in $1\frac{3}{4}$ hour.

Trépied observed it daily from Jan. 13 to 18 without noticing anything very remarkable, but on Jan. 19 the aspect of the nucleus had so changed that it was difficult to realise that the same object was being scrutinised. The head then exhibited 3 zones, as in Fig. 188.

"The interior and most brilliant zone was almost circular, and remarkable owing to its milky aspect: it stood out sharply from the adjoining zone and was of a leaden hue: outside this second zone came the ordinary nebulosity of the tail, having on the south-west side a parabolic outline.

The nucleus had undergone a considerable lengthening: it consisted of two distinct parts of very different brilliancy united by a very well marked twisted link (*étranglement*) which occupied almost the centre of the inner circular zone. The Southern

Fig. 188.



PONS'S COMET: Jan. 19, 1884. (*Trépied.*)

part of the nucleus, which was by far the brightest, was terminated by an elliptic arc very sharply defined and tangential to the circumference of the zone; the Northern part on the contrary was suddenly cut off at the extremity of the diameter, whose direction coincided with that of the axis of the nucleus. This direction was almost exactly identical with that of the axis of the tail. On January 20 the nucleus and the nebulosity which surrounded it had resumed their accustomed aspect. I observed the comet up till the end of the 1st week in February without being able to detect any changes like that which happened on Jan. 19. It follows therefore that the transformations in question must have run their course in a few hours; and herein consists the remarkable character of the whole phenomenon."

Trépied's observations accord generally with those of Perrotin, Thollon and Rayet, which apply however to the date of Jan. 13. It would appear therefore to follow that the changes in this comet, whatever their nature, were in some sense periodic—a circumstance additionally remarkable.

No. 4, Olbers's comet, came back to perihelion in 1887. It was discovered by Brooks in America on Aug. 24.

No. 6. The comet which has the most interesting pedigree is undoubtedly that which bears the name of our illustrious countryman Halley; and as its history will, moreover, serve to exemplify various remarks made in previous pages on the nature and appearance of comets, I cannot do better than give a summary of the said history from the time of the comet's last appearance, in 1835, back to the earliest ages.

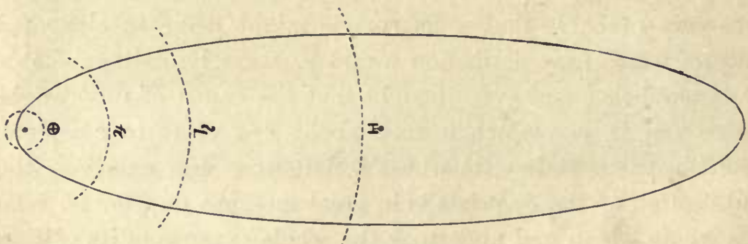
A few years after the advent of the celebrated comet of 1680, Sir I. Newton published his *Principia*, in which he applied to the orbit of that comet the Theory of Gravitation first promulgated in that work. He explained the method of determining, by geometrical construction, the visible portion of the path of a body of this kind, and invited astronomers to apply these principles to the various recorded comets. He considered that it was very probable that some comets might move in elongated ellipses which near perihelion would be scarcely distinguishable from parobolas, and even thought that the comet of 1680 might be moving in one which it took about 575 years to complete. The illustrious Halley (to whose solicitations and exertions the publication of the *Principia* is in great measure due, for he bore the whole labour and undertook the whole expense of its editing and publication) also took this view. But although we now know that the period of that comet is far longer and is in fact measured by thousands of year, Halley's investigations in a subsequent instance led him to a conjecture which was fully substantiated. He undertook the labour of examining the circumstances attending all the comets previously recorded with a view to ascertain whether any, and, if so, which, of them, appeared to follow the same path. Careful investigation soon proved that the orbits of the comets of 1531 and 1607 were similar, and that they were, in fact, the same as that followed by the comet of 1682, seen by himself. He suspected therefore

Fig. 189.

HALLEY'S COMET, JAN. 9, 1683 (N.S.), SHEWING LUMINOUS SECTOR DRAWN BY HEVELIUS[r].

(and rightly too, as the sequel showed) that the appearances at these 3 epochs were produced by the 3 successive returns of one and the same body, and that consequently its period was somewhere about 75½ years. There were nevertheless 2 circumstances which might be supposed to offer some difficulty, inasmuch as it appeared that the intervals between the successive returns were not precisely equal, and that the inclination of the orbit was not exactly the same in each case. Halley, however, "with a degree of sagacity which, considering the state of knowledge at the time, cannot fail to excite unqualified admiration, observed

Fig. 190.



PLAN OF THE ORBIT OF HALLEY'S COMET COMPARED WITH THE ORBITS OF CERTAIN PLANETS.

that it was natural to suppose that the same causes which disturbed the planetary motions would likewise act on comets;" in other words, that the attraction of the planets would exercise

[r] *Annus climactericus*, p. 139.

some influence on comets and their motions. The truth of this idea we have already seen exemplified in the case of the comet of 1770. In fine, Halley found that in the interval between 1607 and 1682 the comet passed so near Jupiter that its velocity must have been considerably increased, and its period consequently shortened; he was, therefore, induced to *predict* its return about the end of 1758 or the beginning of 1759. He thus plaintively wrote on the subject:—"Wherefore if it should return according to our prediction about the year 1758 impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." Although Halley did not survive to see his prediction fulfilled, yet, as the time drew near, great interest was manifested in the result, more especially as Clairaut had named April 13, 1759, as the day on which the perihelion passage would take place. It was not destined, however, that a professional astronomer should be the first[8] to detect the comet on its anticipated return; that honour was reserved for a farmer near Dresden, named Palitzsch, who was also a student of Nature and who saw it on the night of Christmas-day, 1758. But few observations were made before the perihelion passage (on March 12), owing to the comet's proximity to the Sun; during the months of April and May, however, it was seen throughout Europe, although to the best advantage only in the Southern hemisphere. On May 5 it had a tail 47° long.

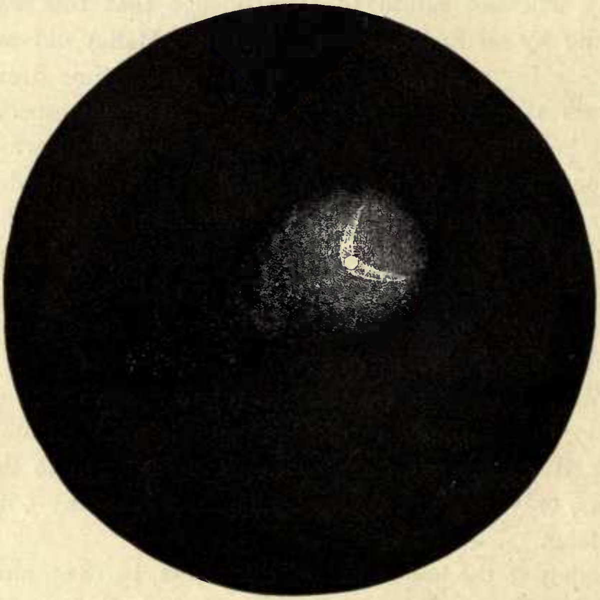
Previously to the last return of this comet, in 1835, numerous preparations were made to receive it. Early in that year Rosenberger, of Halle, published a memoir, in which he announced that the perihelion passage would take place on Nov. 11, though Damoiseau and Pontécoulant both fixed upon a somewhat earlier period.

Let us now see how far these expectations were realised. The comet was seen at Rome on Aug. 5; as it approached the Sun

[8] It was stated by Prof. R. Grant in a lecture at the Royal Institution in 1870, that Messier detected this comet at an early date, but was ordered to hold his tongue. I do not know what authority there is for this statement.

it gradually increased both in magnitude and brightness, but did not become visible to the naked eye till Sept. 20. On Oct. 19 the tail had attained a length of fully 30°. The comet was soon afterwards lost in the rays of the Sun, and passed through its perihelion on Nov. 15, or within 4 days of the time named by Rosenberger. It reappeared early in Jan. 1836, and was observed in the South of Europe and at the Cape till the middle of

Fig. 191.



HALLEY'S COMET, 1835, OCT. 11. (*Smyth.*)

May, when it was finally lost to view, not to be seen again till the year 1910[t].

We have seen above that Halley traced his comet back to the year 1531; we must now, therefore, briefly review its probable history prior to that date, as made known by the labours of modern astronomers. Halley surmised that the great comet of

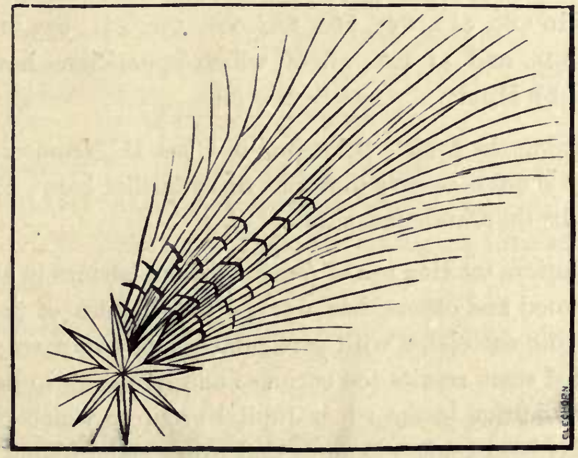
[t] Drawings by Bessel will be found in the *Ast. Nach.*, vol. xiii. Nos. 300–2. Feb. 20, 1836.

Fig. 192. *Plate* XXIV.

HALLEY'S COMET, 1066. (*From the Bayeux Tapestry.*)

1456 was identical with the one observed by him in 1682, and Pingré converted Halley's suspicion into a certainty. The preceding return took place, as Laugier has shown, in 1378, when the comet was observed both in Europe and China; but it does not appear to have been so bright in that year as in 1456. In Sept. 1301 a great comet is mentioned by nearly all the historians of the period. It was seen as far North as Iceland. It exhibited a bright and extensive tail, which stretched across a considerable

Fig. 193.



HALLEY'S COMET, 684. (*From the Nuremberg Chronicle.*)

part of the heavens. This was most likely Halley's comet. The previous apparition is not so well ascertained, but it most likely occurred in July 1223, when it is recorded in an ancient chronicle that a wonderful sign appeared in the heavens shortly before the death of Philip Augustus of France, of which event it was generally considered to be the precursor. It was only seen for 8 days. Although but little information is possessed about it, and that of a very vague character, yet it seems probable that this was Halley's comet. In April 1145 a great comet is mentioned by European historians, which is one of the most certain of our series of returns. In April 1066 an important comet became visible which astonished Europe. It is minutely, though not very clearly, described in the Chinese annals; and the path there assigned to it is found to agree with elements which bear a great resemblance to those of Halley's comet. In England it was considered the forerunner of the victory of William of Normandy, and was looked upon with universal dread. It was equal to the Full Moon in size, and its train, at first small, increased to a wonderful length. Almost every historian and writer of the 11th century bears witness to the splendour of the comet of 1066, and there can be but little doubt that it was Halley's. Previous to this year the comet appeared in 989, 912, 837, 760, 684, 608, 530, 451, 373, 295, 218, 141, 66 A.D., and 11 B.C., all of which apparitions have been identified by Hind[u].

Concerning the comets belonging to Class III. (comets of long period), it is not necessary to notice them further here; they will be found in the Catalogue, *passim*.

Flammarion, making use of some previous labours in this field by Kirkwood and others, has worked out the idea of particular comets being associated with particular planets in a way which has yielded some results too curious and interesting to be passed over. In addition to the 1st or Jupiter group to which reference has already been made[x], he finds that every major planet beyond Jupiter seems to have a group of comets attached to it; and moreover, as there is a group of comets without a known planetary leader, he makes bold to speculate that this fact is a proof that a Trans-Neptunian planet exists and will one day be found.

The following are Flammarion's groups, the figures appended representing in Radii of the Earth's orbit the mean distances of the respective planets and the aphelion distances of the respective comets:—

2ND GROUP.

SATURN	9·0 to 10·1
Tuttle's Comet	10·5

[u] *Month. Not.*, vol. x. p. 51. Jan. 1850.

[x] See pp. 401, 402, *ante*.

3RD GROUP.

URANUS	18·3 to 20·1
Comet of 1866 (i.) and November Meteors	19·7
Comet of 1867 (i.)	19·3

4TH GROUP.

NEPTUNE	29·8 to 30·3
Comet of 1852 (iv.) (Westphal)	29–32
Comet of 1812 (Pons)	33
Comet of 1846 (iv.) (Di Vico)	34
Comet of 1815 (Olbers)	34
Comet of 1847 (v.) (Brorsen)	35
Halley's Comet	35

5TH GROUP.

Trans-Neptunian planet?	47 to 48?
Comet of 1862 (iii.), and August Meteors	49
Comet of 1532 and 1661...	48

Flammarion finally hints at the speculation that the undiscovered planet must, if it be related to the comets of the 5th group, revolve at somewhere about twice the distance of Neptune, say, in a period of 300 years[y].

[y] *L'Astronomie,* vol. iii. p. 89, March 1884. I have corrected several important mistakes or misprints in the French original.

CHAPTER III.

REMARKABLE COMETS.

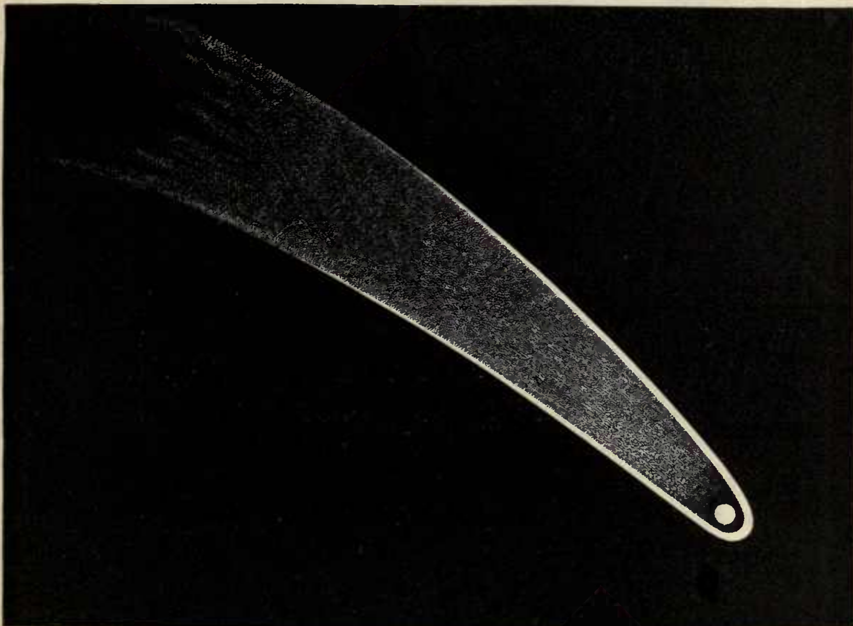
The Great Comet of 1811.—*The Great Comet of* 1843.—*The Great Comet of* 1858. —*The Comet of* 1860 (iii.).—*The Great Comet of* 1861.—*The Comet of* 1862 (iii.).—*The Comet of* 1864 (ii.).—*The Comet of* 1874 (iii.).—*The Comet of* 1882 (iii.).

THE comets which might be included under the above head are so numerous as to make it impossible that all should receive full attention. I must therefore limit myself to some few of the most interesting, premising that Grant includes the following comets under the designation "remarkable":—

1066	1531	1682	1823
1106	1556	1689	1835
1145	1577	1729	1843
1265	1607	1744	1858
1378	1618	1759	1861
1402	1661	1769	
1456	1680	1811	

The Comet of 1811 (i.) is one of the most celebrated of modern times. It was discovered by Flaugergues, at Viviers, on March 26, 1811, and was last seen by Wisniewski at Neu-Tscherkask, on Aug. 17, 1812. In the autumnal months of 1811 it shone very conspicuously, and its considerable Northern declination caused it to remain visible throughout the night for many weeks. The extreme length of the tail at the beginning of October was about 25°, and its breadth about 6°. Sir W. Herschel paid particular attention to this comet, and the observations which he made are very valuable. He states that it had a well-defined nucleus, the diameter of which he found by careful measurement to be 428 miles; further, that the nucleus was of a ruddy hue, though the surrounding nebulosity had a bluish-green tinge [a]. This comet

Fig. 194.



THE GREAT COMET OF 1811.

undoubtedly is a periodical one. Argelander, whose investigation of the orbit is the most complete that has been carried out, assigned to it a period of 3065 years, subject to an uncertainty of only 43 years [b]. The aphelion distance is 14 times that of Neptune, or, more exactly, 40,121,000,000 miles.

The Comet of 1843 (i.) was one of the finest that has appeared during the present century. It was first seen in the Southern hemisphere towards the end of the month of February, and during

[a] *Phil. Trans.*, vol. cii. pp. 118, 119, 121.
[b] *Berlin. Ast. Jahrbuch*, 1825, p. 250.

the first fortnight in March it shone with great brilliancy. It was not visible in England until after the 15th, when its splendour had much diminished; but the suddenness with which it made its appearance added not a little to the interest which it excited. The general length of the tail during March was about 40°, and its breadth about 1°. The orbit of this comet is remarkable for its small perihelion distance, which did not exceed, according to the most reliable calculations, 538,000 miles; and the immense velocity of the comet in its orbit, when near the perihelion, occasioned some extraordinary peculiarities. Thus between Feb. 27 and 28 it described upon its orbit an arc of 292°. Supposing it to revolve in an ellipse, this would leave only 68° to be described during the time which would elapse before its next return to perihelion.

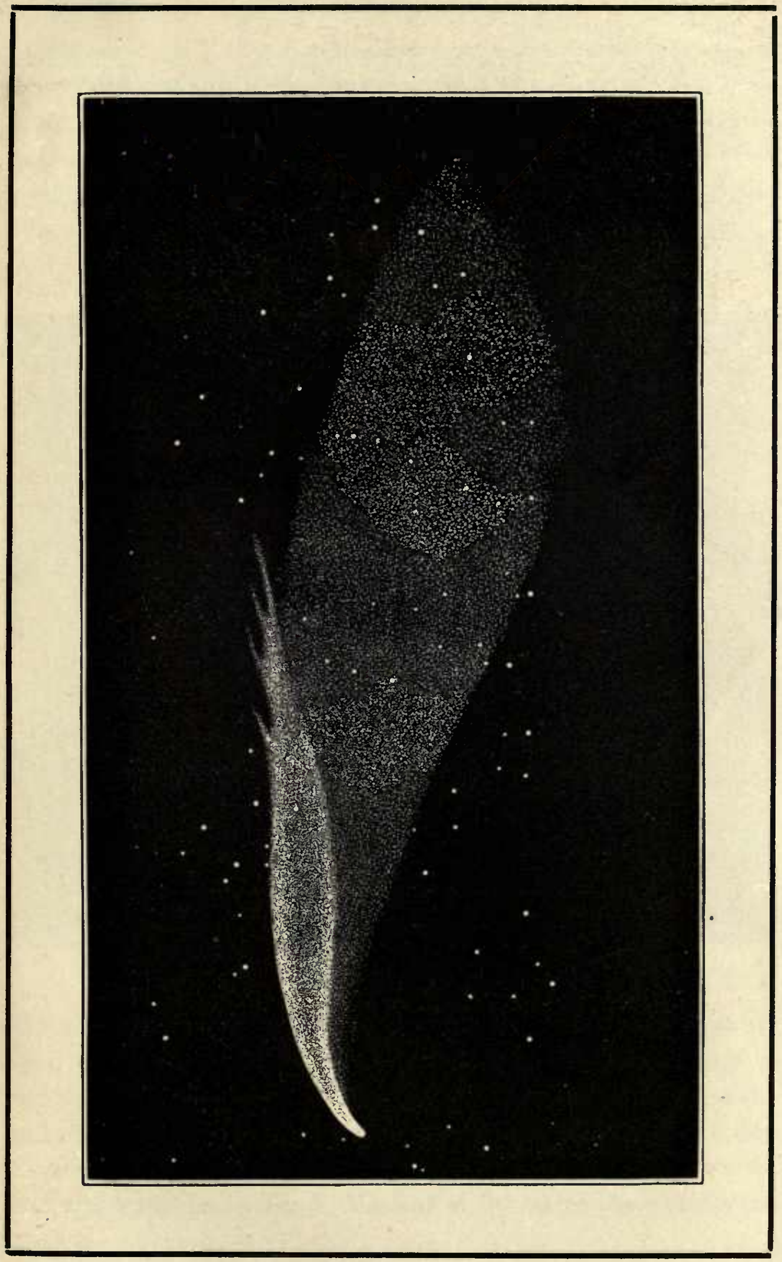
It has been thought by some that this comet was identical with those of 1668 and 1689, but so little is known *for certain* about this latter that we are not yet in a position to admit or deny the identity of the 3 bodies. In the work to which reference is made in the note the question is discussed with great ability [c].

The Comet of 1858 (vi.). On June 2 in that year, Dr. G. B. Donati, at Florence, descried a faint nebulosity slowly advancing towards the North, and near the star λ Leonis. Owing to its immense distance from the Earth (240,000,000 miles), great difficulty was experienced in laying down its orbit. By the middle of August, however, its future course and the great increase in its brightness which would take place in September and October were clearly foreseen. Up to this time (middle of August) it had remained a faint object, not discernible by the unaided eye. It was distinguished from ordinary telescopic comets only by the extreme slowness of its motion (in singular contrast to its subsequent career), and by the vivid light of its nucleus: "the latter peculiarity was of itself prophetic of a splendid destiny." Traces of a tail were noticed on Aug. 20, and on Aug. 29 the comet was

[c] E. J. Cooper, *Cometic Orbits*, pp. 159–69. For something more concerning the supposed identity of this comet see *post*, under the head of Comet iii., 1882.

DONATI'S COMET: October 5, 1858.

(*Drawn by Pape.*)

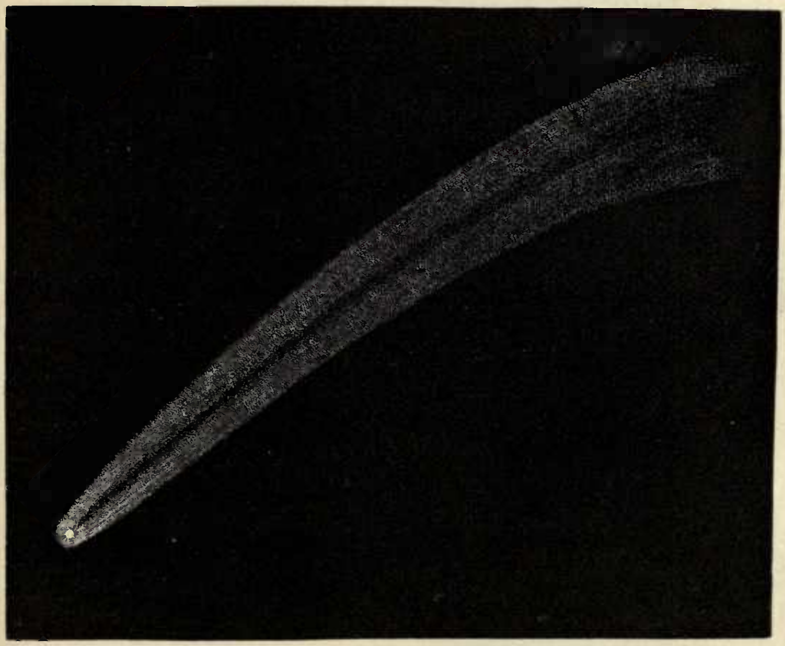


DONATI'S COMET: October 9, 1858.

(*Drawn by Pape.*)

faintly perceptible to the naked eye; for a few weeks it occupied a Northern position in the heavens, and it was therefore seen both in the morning and evening. On Sept. 6 a slight curvature of the tail was noticed, which subsequently became one of its most interesting features. On Sept. 17 the head equalled in brightness a star of the 2nd magnitude, the length of the tail being 4°.

Fig. 197.



DONATI'S COMET, 1858, SEPT. 30. (*Smyth.*)

The comet passed through perihelion on Sept. 29, and was at its least distance from the earth on Oct. 10. Its rapid passage to the Southern hemisphere rendered it invisible in Europe after the end of October, but it was followed at the Santiago-de-Chili and Cape of Good Hope Observatories for some months afterwards, and was last seen by Sir T. Maclear at the latter place on March 4, 1859.

"Its early discovery enabled astronomers, while it was yet scarcely distinguishable in the telescope, to predict, some months in advance, the more prominent particulars of its approaching apparition, which was thus observed with all the advantage of previous preparation and anticipation. The perihelion passage occurred at the most favourable moment for presenting the comet to good advantage. When nearest the earth, the direction of the tail was nearly perpendicular to the line of vision, so that its proportions were seen without foreshortening. Its situation in

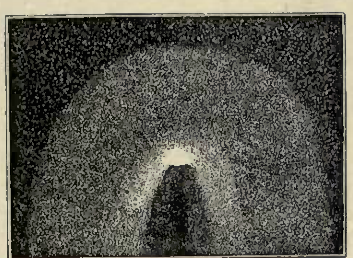
Fig. 198.

DONATI'S COMET, 1858, PASSING ARCTURUS ON Oct. 5.

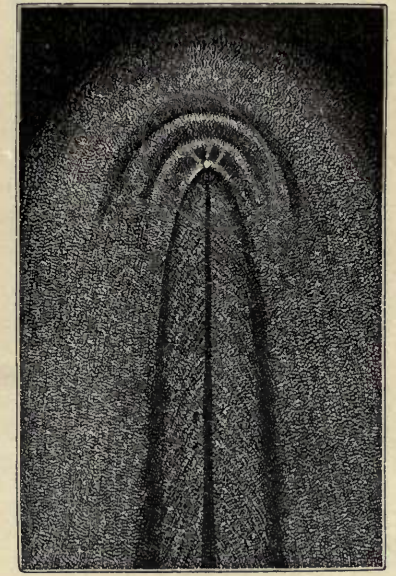
the latter part of its course afforded also a fair sight of the curvature of the train, which seems to have been exhibited with unusual distinctness, contributing greatly to the impressive effect of a full-length view."

This comet, though surpassed by many others in size, has not often been equalled in the intense brilliancy of the nucleus, which the absence of the Moon, in the early part of October, permitted to be seen to the very best advantage. There is no doubt that the comet of Donati revolves in an elliptic orbit with a period

September 22. (*Pape.*)

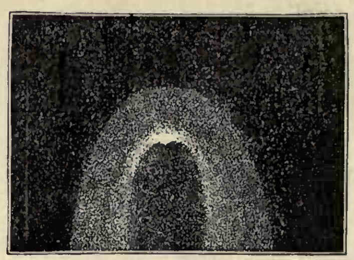


October 6. (*Pape.*)



(*Anon.*)

September 29. (*Pape.*)



October 12. (*Pape.*)

DONATI'S COMET, 1858: Views of the Coma.

of about 2000 years (Stampfer, 2138[y]; Löwy, 2040[y]; Von Asten, 1879[y]).

The following is a table of the dimensions of the comet's nucleus and tail, at the undermentioned dates[d]:—

Date.	Diameter of Nucleus.		Length of Tail.	
1858.	″	Miles.	°	Miles.
July 19	5	= 5600		...
Aug. 30	6	= 4660	2	= 14,000,000
Sept. 8	3	= 1980	4	= 16,000,000
„ 12	...		6	= 19,000,000
„ 23	3	= 1280	5	= 12,000,000
„ 25	...		11	= 17,000,000
„ 27	...		13	= 18,000,000
„ 28	...		19	= 26,000,000
„ 30	...		22	= 26,000,000
Oct. 2	...		25	= 27,000,000
„ 5	1·5	= 400	33	= 33,000,000
„ 6	3·0	= 800	50	= 45,000,000
„ 8	4·4	= 1120	50	= 43,000,000
„ 10	2·5	= 630	60	= 51,000,000
„ 12	...		45	= 39,000,000

The Comet of 1860 (iii.). In the latter end of June 1860, a comet of considerable brilliancy suddenly made its appearance in the Northern circumpolar regions. Bad weather prevented it from being generally observed in England, but in the South of Europe it was well seen; copies of some drawings made at Rome are annexed. [Plate XXVIII.]

Few comets created greater sensation than the Great Comet of 1861 (ii. of that year). It was discovered by Mr. J. Tebbutt, an amateur observer in New South Wales, on May 13, previous to its perihelion passage, which took place on June 11. Passing from the Southern hemisphere into the Northern, it became

[d] G. P. Bond, *Math. Month. Mag.*, Boston, U.S., Nov. and Dec. 1858. Mr. Bond subsequently published a magnificent memoir on this comet in vol. ii. of the *Annals of the Harvard College Observatory*. Cambridge, Mass., 1862.

visible in this country on June 29, though it was not generally seen till the next evening. So many accounts of it were published that selection is difficult, but the following pages will be found to contain an epitome of the most noticeable features [e].

Sir J. Herschel observed it in Kent. He says:—

"The comet, which was first noticed here on *Saturday* night, June 29, by a resident in the village of Hawkhurst (who informs me that his attention was drawn to it by its being taken by some of his family for the Moon rising), became conspicuously visible on the 30th, when I first observed it. It then far exceeded in brightness any comet I have before observed, those of 1811 and the recent splendid one of 1858 not excepted. Its total light certainly far surpassed that of any fixed star or planet, except perhaps Venus at its maximum. The tail extended from its then position, about 8 or 10° above the horizon, to within 10 or 12° of the Pole-star, and was therefore about 30° in length. Its greatest breadth, which diminished rapidly in receding from the head, might be about 5°. Viewed through a good achromatic, by Peter Dollond, of 2¾-inches aperture and 4-feet focal length, it exhibited a very condensed central light, which might fairly be called a nucleus; but, in its then low situation, no other physical peculiarities could be observed. On the 1st instant it was seen early in the evening, but before I could bring a telescope to bear on it clouds intervened, and continued till morning twilight. On the 2nd (Tuesday), being now much better situated for observation, and the night being clear, its appearance at midnight was truly magnificent. The tail, considerably diminished in breadth, had shot out to an extravagant length, extending from the place of the head above o of the Great Bear at least to π and ρ Herculis; that is to say, about 72°, and perhaps somewhat further. It exhibited no bifurcation or lateral offsets, and no curvature like that of the comet of 1858, but appeared rather as a narrow prolongation of the Northern side of the broader portion near the comet than as a thinning off of the latter along a central axis, thus imparting an unsymmetrical aspect to the whole phenomenon.

"Viewed through a 7-feet Newtonian reflector of 6-inches aperture the nucleus was uncommonly vivid, and was concentrated in a dense pellet of not more than 4″ or 5″ in diameter (about 315 miles). It was round, and so very little *woolly* that it might *almost* have been taken for a small planet seen through a dense fog; still so far from *sharp* definition as to preclude any idea of its being a solid body. No sparkling or star-light point could, however, be discerned in *its* centre with the power used (96), nor any separation by a darker interval between the nucleus and the cometic envelope. The gradation of light, though rapid, was continuous. Neither on this occasion was there any *unequivocal* appearance of that sort of fan or sector of light which has been noticed on so many former ones.

"The appearance of the 3rd was nearly similar, but on the 4th the fan, though feebly, was yet certainly perceived; and on the 5th was very distinctly visible. It consisted, however, not in any vividly radiating jet of light from the nucleus of any well-defined form, but in a crescent-shaped cap formed by a very delicately graduated condensation of the light on the side towards the Sun, connected with the nucleus,

[e] By far the most complete account is that by the Rev. T. W. Webb in the *Month. Not.*, vol. xxii. p. 305. 1862.

June 26.

June 28.

June 30.

July 1.

July 6.

July 8.

COMET III: 1860.

(*Drawn by Cappelletti and Rosa.*)

and what may be termed the *coma* (or spherical haze immediately surrounding it), by an equally delicate graduation of light, very evidently superior in intensity to that on the opposite side. Having no micrometer attached, I could only estimate the distance of the brightest portion of this crescent from the nucleus at about 7′ or 8′, corresponding at the then distance of the comet to about 35,000 miles. On the 4th (Thursday) the tail (preserving all the characters already described on the 2nd) passed through *α* Draconis and *τ* Herculis, nearly over *η* and *ε* Herculis, and was traceable, though with difficulty, almost up to *α* Ophiuchi, giving a total length of 80°. The northern edge of the tail, from *α* Draconis onwards, was perfectly straight,—not in the least curved,—which, of course, must be understood with reference to a great circle of the heavens.

"Viewed, on the 5th, through a doubly refracting prism well achromatised, no certain indication of polarisation in the light of the nucleus and head of the comet could be perceived. The two images were distinctly separated, and revolved round each other with the rotation of the prism without at least any marked alternating difference of brightness. Calculating on Mr. Hind's data, the angle between the Sun and earth and the comet must then have been 104°, giving an angle of incidence equal to 52°, and obliquity 38°, for a ray supposed to reach the eye *after a single* reflection from the cometic matter. This is not an angle unfavourable to polarisation, but the reverse. At 66° of elongation from the Sun (which was that of the comet on the occasion in question), the blue light of the sky is very considerably polarised. The constitution of the comet, therefore, is analogous to that of a cloud; the light reflected from which, as is well known, at that (or any other) angle of elongation from the Sun, exhibits no signs of polarity."

Hind stated that he thought it not only possible, but even probable, that in the course of Sunday, June 30, the Earth passed through the tail of the comet at a distance of perhaps two-thirds of its length from the nucleus. The head of the comet was in the ecliptic at 6 P.M. on June 28, at a distance from the Earth's orbit of 13,600,000 miles on the inside, its longitude, as seen from the Sun, being 279° 1′. The earth at that moment was 2° 4′ behind that point, but would arrive there soon after 10 P.M. on Sunday, June 30. The tail of a comet is seldom an exact prolongation of the radius vector, or line joining the nucleus with the Sun; towards the extremity it is almost invariably curved; or, in other words, the matter composing it lags behind what would be its situation if it travelled with the same velocity as the nucleus. Judging from the amount of curvature on the 30th, and the direction of the comet's motion, Hind thought that the Earth very probably encountered the tail in the early part of that day, or, at any rate, that it was certainly in a region which had been swept over by the cometary matter but a short time previously.

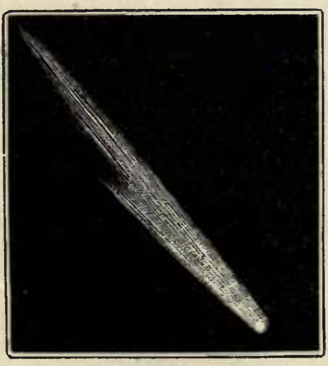
In connexion with this subject, he added that on the evening of June 30, while the comet was so conspicuous in the northern heavens, there was a peculiar phosphorescence or illumination of the sky, which he attributed at the time to an auroral glare; it was remarked by other persons as something unusual, and, considering how near we must have been on that evening to the tail of the comet, it may perhaps be a point worthy of consideration whether such an effect might not be attributable to this proximity. If a similar illumination of the heavens had been remarked generally on the Earth's surface it would have been a very significant fact.

Mr. Lowe, of Highfield House, confirmed Mr. Hind's statement of the peculiar appearance of the heavens on June 30. The sky, he says, had a yellow auroral glare-like look, and the Sun, though shining, gave but feeble light. The comet was plainly visible at a quarter to 8 o'clock (during sunshine), while on subsequent evenings it was not seen till an hour later. In confirmation of this, he adds that in the Parish Church the vicar had the pulpit candles lighted at 7 o'clock, which proves that a sensation of darkness was felt even while the Sun was shining. Though he was not aware that the comet's tail was surrounding our globe, yet he was so struck by the singularity of the appearance, that he recorded in his day-book the following remark:—"A singular yellow phosphorescent glare, very like diffused Aurora Borealis, yet, being daylight, such Aurora would scarcely be noticeable." The comet itself, he states, had a much more hazy appearance than at any time after that evening.

De La Rue attempted to photograph the comet. After 3 minutes' exposure in the focus of his 13-inch reflector the comet had left no impression upon a sensitised collodion plate, although a neighbouring star, π Ursæ Majoris—close to which the comet passed on the night of July 2—left its impression twice over, from a slight disturbance of the instrument. De La Rue also, at that time, fastened a portrait camera upon the tube of his telescope, and, with the clock motion in action, exposed a collodion plate for 15 minutes to the open view of the comet with-

July 8. (*Webb.*)

July 2. (*Brodie.*)

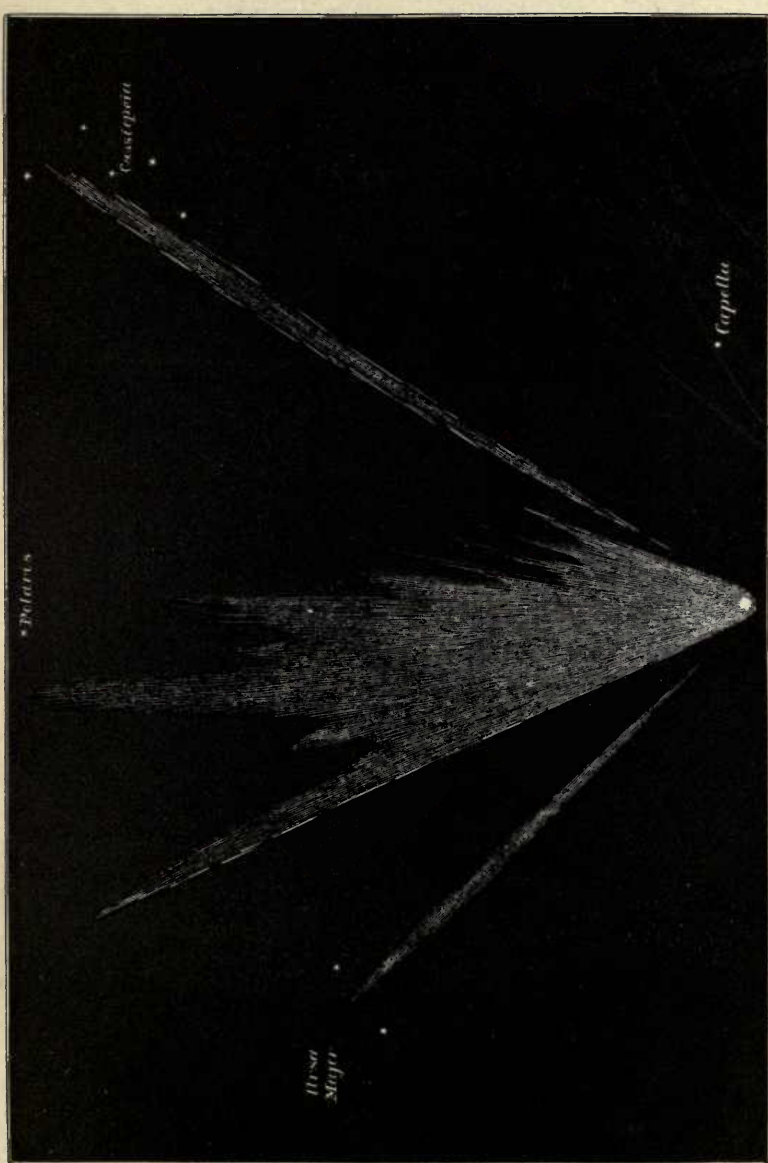


July 2. (*Brodie.*)

July 2. (*Chambers.*)

THE GREAT COMET OF 1861.

Fig. 214. Plate XXX.



THE GREAT COMET OF 1861, on June 30.

(Drawn by G. Williams.)

out any other effect than the general blackening of the surface by the skylight, together with impressions of several fixed stars in the neighbourhood.

Respecting the polarisation of the light of the comet, Secchi said:—

"The most interesting fact I observed was this: the polarisation of the light of the comet's tail and of the rays near the nucleus was very strong, and one could even distinguish it with the band polariscope; but the nucleus presented no trace of polarisation, not even with Arago's polariscope with double coloured image. On the contrary, on the evenings of July 3, and following days, the nucleus presented decided indications, in spite of its extreme smallness, which, on the evening of July 7, was found to be hardly 1″.

"I think this a fact of great importance, for it seems that the nucleus on the former days shone by its own light, perhaps by reason of the incandescence to which it had been brought by its close proximity to the Sun.

"During the following days the tail has been constantly diminishing, but it is remarkable that it has always passed near to α Herculis, and that it reached to the Milky Way up to July 6. It would seem that the two tails were nearly independent, and that on July 5 the length and straightness had gone off from the large one, and that this bent itself to the southern side. Last night (July 7) the long train was hardly perceptible. The light was polarised in the plane of the tail."

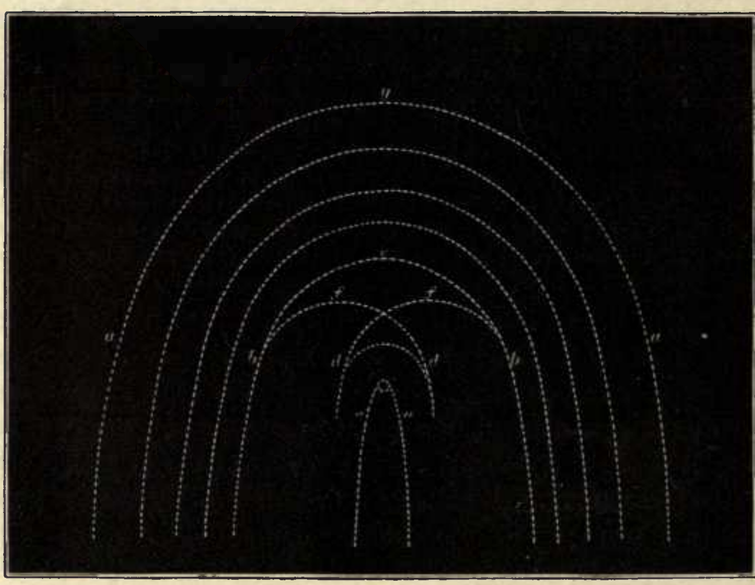
Observations on the polarisation of the light of the comet were also made by M. Poey, at Passy. This gentleman observed the polarisation in Donati's comet at Havannah in 1858, in which case the light was polarised in a plane passing through the Sun, the comet, and the observer; but, in the case of the present comet, "the plane of polarisation seemed to pass sensibly perpendicular to the axis of the tail," which, he thought, might have been owing to atmospheric refraction.

The comet of 1862 (iii.), though not one of first-class brilliancy, was nevertheless a very interesting object, particularly on account of the fact that a jet of light, frequently altering in form, was observed for a long time to emanate from its nucleus. Annexed are some views drawn by the late Prof. Challis of Cambridge. This comet had a tail, which, on Aug. 27, was 20° long.

The comet of 1864 (ii.), visible in August, had a head unusually large, scarcely less than ½° in diameter. To the naked eye it resembled on the 4th of that month a dull blurred star of the 3rd magnitude, but in the telescope it appeared as a circular mass of nebulous matter with a central condensation very similar to the well-known planetary nebula in Virgo. There was a faint tail, but it presented no special feature of interest.

The comet of 1874 (iii.), discovered by Coggia at Marseilles on April 17, was one of considerable interest. The drawing from which Plate XXXII has been engraved (and of which figure 215 is a skeleton outline), was made with an achromatic telescope of $8\frac{1}{2}$ inches aperture and $11\frac{1}{2}$ feet local length, on July 13, the

Fig. 215.



COGGIA'S COMET OF 1874.

Skeleton outline on July 13. (*Brodie.*)

a, g, a. Undefined outline of nebulous head.
b, c, b. Fairly defined outline of second envelope.
d, d. Sharply defined outline of first envelope, semicircular, and very bright.
e, e. Very sharply defined clear dark space between bifurcation of tail, free from nebulosity.
f, f. Singular eccentric envelopes, sharply defined, fading away at and into *b b.* The centres of those envelopes were at *d.*
g, c. Between these two points several envelopes concentric with *d d* were traceable.

most favourable night during its appearance, when its position in the heavens, its contiguity to the Earth, and the absence of twilight are jointly taken into consideration. The Southward motion of the comet was so rapid that on July 14 the presence

Aug. 7.

Aug. 18.

Aug. 18.

Aug. 19.

Aug. 22.

Aug. 29.

COMET III, 1862.

(*Drawn by Challis.*)

COGGIA'S COMET, 1874: on July 13.

(*Drawn by Brodie.*)

of twilight greatly interfered with the details shown in the drawing. The following description is from the pen of Mr. F. Brodie:—

"The head of the comet presented the great peculiarity of having two eccentric envelopes in addition to the ordinary bright envelope immediately surrounding the nucleus. The first envelope was a bright and sharply defined semicircle surrounding the nucleus: the two eccentric envelopes were nearly as bright, and also very sharply defined, also semicircular, having their centres placed (about) on the edge of the first envelope, and intersecting each other. The second centrical envelope just embraced both these eccentric envelopes, and was about half the width of the nebulous head of the comet. Between this second envelope and the ill-defined outline of the head (that is, between *c* and *g*) there were faintly marked outlines of other concentric envelopes. The nucleus, which, according to Hind, was 4000 miles in diameter, appeared to be somewhat flattened on the side opposite to the Sun. From this side also the head of the comet divided itself into two distinct parts forming the commencement of the tail: for some distance this bifurcation was remarkably sharply defined, suggesting an intense repulsive force acting upon the nucleus of the comet; and the space enclosed between this bifurcation was strikingly free from nebulous matter, until at some little distance away from the nucleus the sharp definition faded into the general nebulosity of the tail."

The following remarks[f] on this comet are by two French observers, MM. Wolf and Rayet:—

"After having maintained for many days a great sameness of form, on June 22 a series of changes in the shape of the head of the comet commenced. On that day the comet, viewed with a Foucault telescope of 40 centimetres, appeared to be enclosed in the interior of a very elongated parabola. Starting from the nucleus, which was placed as it were at the focus of the curve, the brightness decreased gradually towards the summit: but in the interior of the parabola the diminution of the brightness was sudden, and the boundary-line exhibited another parabola a little more open than the first, and having at its own summit the brilliant nucleus itself. The outline of the parabola which passed through the nucleus was prolonged so as to form the lateral boundaries of the tail, the edges of which were well defined and were much brighter than the interior parts. This tail had then the appearance of a luminous envelope hollow in the inside. The nucleus was always very sharp. On July 1 the general form of the comet remained the same; it appeared always to possess a parabolic outline at its exterior edge. The nucleus however jutted out into the interior of the second parabola, and the opposite margins of the tail were not strictly symmetrical. The West side, that is to say the side which had the greatest R.A., was very sensibly brighter than the other. . . . From July 5, the want of symmetry spoken of above became more and more marked, and near the head the decrease of the brightness became less regular. On July 7, the contrast between the two branches was striking, the Western branch of the tail being about twice as bright as the Eastern. At the same time the nucleus appeared to be becoming diffused, and it seemed to fade away in the direction of the head of the comet, although still

[f] Translated for this work from Guillemin's *Comètes*, p. 293.

sharply defined on the side nearest the tail; one could not fail to remark its resemblance to an open fan. . . . Our last observation of the comet was made on July 14 at 9.30 P.M.: important changes in the aspect of the head had manifested themselves. The fan of light had disappeared on the West side, and was replaced by a long spur of light which was traceable for a considerable distance across the head; on the West side the remnant of the fan terminated abruptly, and the boundary-line there made but a small angle with the main axis of the comet. On this same occasion two rays of light were visible—two jets as they might be deemed—thrown forwards, the one to the right and the other to the left; these luminous rays seemed to have their origin at the edge of the fan of which they formed a sort of prolongation. The ray which pointed towards the East projected well forwards, and being bent round towards the tail soon reached the preceding edge of the comet; it was faint and hardly surpassed the nebulosity in brilliancy. The ray projected towards the West was much more brilliant, and was similarly bent round towards the tail, which it assisted in providing with a bright exterior edge."

On July 13, the comet was 35,000,000 miles from the Earth, and although it approached to within 26,000,000 miles on July 21, it was then too nearly in Conjunction with the Sun to be seen. The tail was calculated by Hind to have increased in actual length from 4,000,000 miles on July 3 to 25,000,000 miles on July 19, augmenting in angular length from 4° to upwards of 43°. On the evening on which Mr. Brodie's sketch was taken the tail appeared to be rather arched towards the western horizon, and could be traced by the naked eye for nearly 20°. This comet certainly revolves in an elliptic orbit, but the period is long. Geelmuyden's value is $10,445^y$; Seyboth's, 5711^y. In either case the semi-axis major must be some 300 or 400 times the Earth's mean distance from the Sun.

The comet of 1882 (iii.) was in some respects one of the most remarkable of modern times. It was conspicuously visible to the naked eye for some weeks in September, and altogether remained in sight for the long period of 9 months; but these facts, though noteworthy, would not have called for any special remark had not other peculiarities been forthcoming to distinguish this comet from almost all others. Briefly stated, its special features were, that the head underwent changes in the nature of disruptions; that the tail may have been tubular; that the extremity of the tail was not only bifid but totally unsymmetrical; and that on one occasion the comet seems to have thrown off a mass of matter which became, and for several days was observed as, a distinct comet.

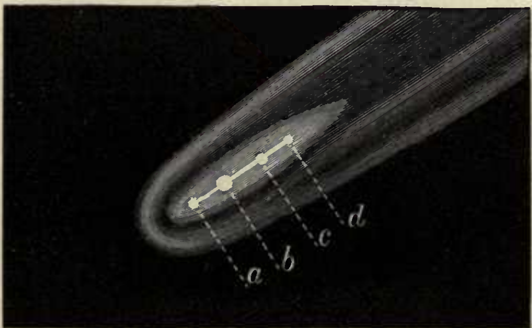
Many observers noticed the changes which took place in the nucleus and head. Prince said:—

"Oct. 13. I could notice, however, that there was a decided change in the appearance of the nucleus. Instead of being of an oval shape, it had become a long flickering column of light in the direction of the tail."

"Oct. 20.—I noticed, however, at once, that a still further change had occurred in the nucleus since the 13th, which amounted, in fact, to its disruption into at least 3 portions."

"October 23.—The disruption of the nucleus which I had noticed on the 20th was now fully apparent. The nucleus proper had become quite linear, having upon it the 4 distinct points of condensation which I have endeavoured to represent in the subjoined sketch.

Fig. 223.



THE GREAT COMET OF 1882. FORMATION OF THE NUCLEUS. (*C. L. Prince.*)

"It must be understood that the accompanying woodcut is to be considered rather as a *diagram* of the head of the comet than as a view of what I actually observed, and that the *points* in question are somewhat exaggerated in size, as well as the linear character of the nucleus itself. I found it was very difficult to represent, by means of a wood-block, such a nebulous object; but I think it will serve to illustrate the nature of the wonderful disruption, and the relative distance of the several portions *inter se*: *a* was the most difficult portion to discern; *b* was by far the brightest of all; *c* was considerably less bright than *b*; and *d* was nearly as faint an object as *a*, and not quite so large. The linear nucleus, with these points of condensation upon it, was surrounded by a distinct oblong coma, which was rounded off at the lower extremity, while the upper portion, following the direction of the tail, terminated more decidedly in a point. Mr. G. J. Symons, F.R.S., was with me in the observatory, and his impression was that there were *five* points of condensation, and he remarked that 'the nucleus was like a string of beads.' At intervals I thought there *was* another point of light between *b* and *c*, but as I could not absolutely satisfy myself of its objective existence, I have only represented the four portions, of the presence of which I entertained no doubt whatever. Both Mr. Symons and myself particularly noticed the frequent flickering of the light of the nucleus, which was quite apparent both to the naked eye and in the telescope [g]."

J. F. J. Schmidt published a sketch of the nucleus, as seen by himself, which is not unlike Prince's, and having seen the latter he refers to it as a good representation of what he saw himself. He noticed a vibratory motion in the fan [h].

The tubular character of the comet's tail was suggested by Tempel, who brought out the idea in some striking sketches submitted by him to the Royal Astronomical Society, accompanied, for comparison's sake, by a drawing of the appearance of two hollow glass cylinders as seen in the focus of an eye-piece [i].

The peculiar conformation of the extremity of the tail of this comet will be sufficiently indicated by the accompanying woodcut [k].

Fig. 224.

THE GREAT COMET OF 1882. NAKED-EYE VIEW ON NOV. 14. (*B. J. Hopkins.*)

Most observers noticed this feature, which though rare as respects the comets of the last half century may be conceived to be the shape meant by old writers when they speak (as they often do) of having seen a comet resembling in form a "Turkish scymiter."

Mr. Hopkins himself likened the general form of the tail to the Greek letter γ.

[g] *Month. Not.*, vol. xliii. p. 85, Jan. 1883.

[h] *Ast. Nach.*, vol. cv. No. 2499, March 19, 1883; *Observatory*, vol. vi. p. 157, May 1883.

[i] *Month. Not.*, vol. xliii. p. 322, April 1883.

[k] *Month. Not.*, vol. xliii. p. 90, Jan. 1883.

The last physical peculiarity of the great comet of 1882, to be referred to, its throwing off a mass of matter which became a satellite comet, was recorded by Schmidt at Athens and Barnard and Brooks in America. Perhaps it is going beyond the legiti-

Fig. 225.

THE GREAT COMET OF 1882, ON OCT. 9 AT 4^h A.M. (*Flammarion.*)

mate limits of the available evidence to speak quite as plainly as this, but the fact is clear that Schmidt saw on Oct. 9 and on 2 or 3 later days a nebulous mass in the neighbourhood of the comet, which calculation indicated was cometary matter moving round the Sun in an orbit considerably resembling the orbit of the comet. Brooks's observation was made on Oct. 21: what he saw was a nebulous mass on the opposite side of the comet to Schmidt's mass[l]. With the evidence before us of what happened in 1846 in the case of Biela's comet it is impossible not to draw the inference that the nebulous mass (or masses) was or had been a part of the comet itself; and this theory becomes much strengthened when read in the light of the disruptive changes which the condition of the nucleus underwent, according to the testimony of Prince and others, as above mentioned.

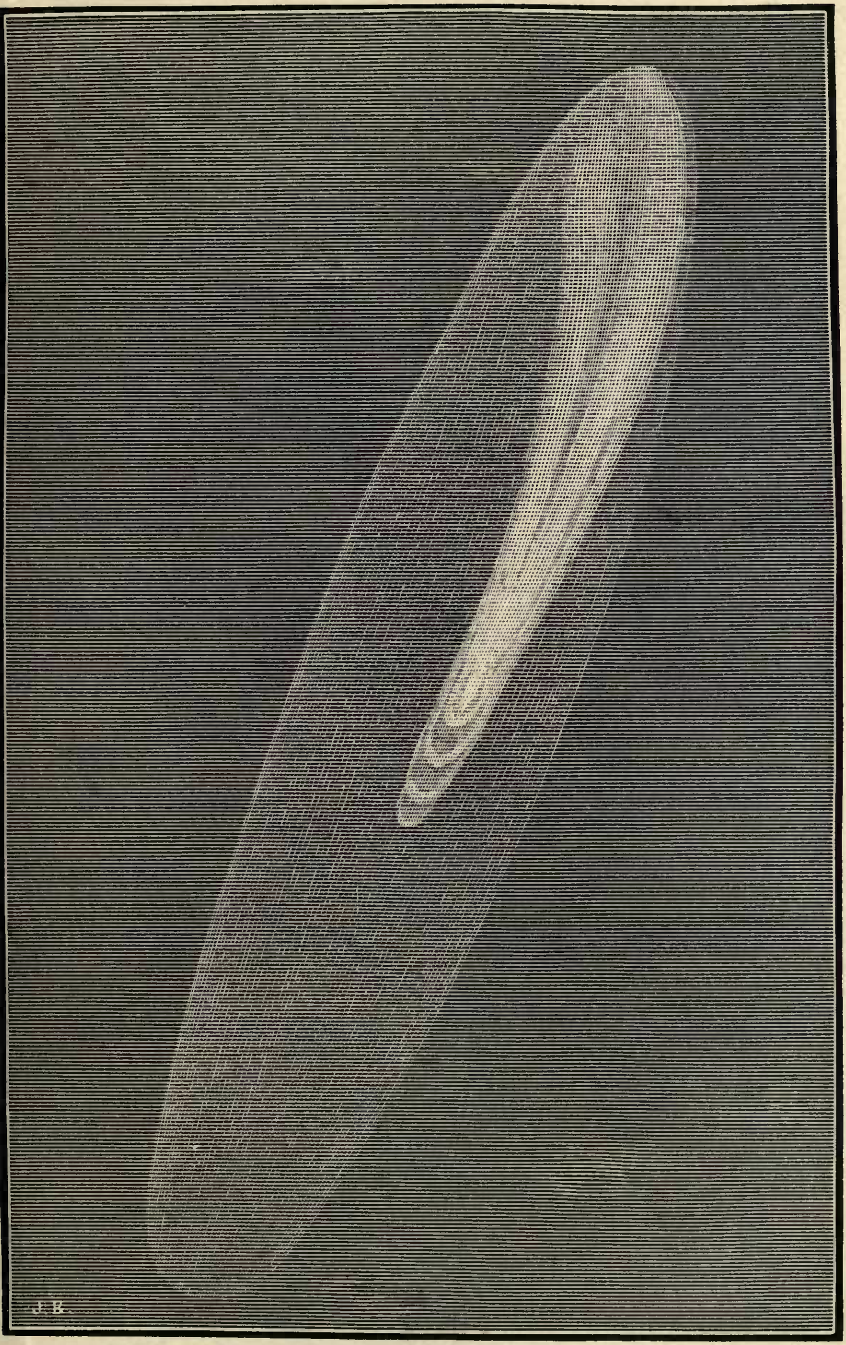
Even the orbit of the comet of 1882 has greatly puzzled astronomers. It was found (see Catalogue I., *post*) that the elements thereof closely resembled those of the comet of 1880 (i.), often spoken of as the "great Southern comet of 1880." This in turn was considered to be a comet moving in an elliptic orbit with a period of about 37 years and to be in fact a return of the celebrated comet of 1843 which caused such a sensation in the March of that year. It remains still a moot point what is the interpretation to be put upon these orbital resemblances. The question is a very speculative one, and it does not seem profitable to discuss the matter more fully at present, except to record the suggestion that the 4 great comets of 1843, 1880, 1882, and 1887 (i.) had at some past time a common origin, but by some process of disintegration the original mass has yielded fragments, which pursuing slightly different paths, arrive at perihelion at irregular intervals[m].

Gen. G. H. Willis observed the comet at sea 70 miles E. of Gibraltar on Oct. 19 at 5 A.M., with the air extremely clear and the wind calm. He says that in appearance the comet was so "extremely delicate, light and airy that it would be almost impossible to depict it on paper." The engraving [Plate XXXIII] is a French reproduction of the original English lithograph[n].

[l] *Sidereal Messenger*, vol. ii. p. 149, Aug. 1883.

[m] *Month. Not.*, vol. xliii. p. 108, Feb. 1883. *Month. Not.*, vol. xlviii. p. 199, Feb. 1888. For various drawings of the comet of 1882 see *Ast. Nach.*, vol. civ. No. 2489, Feb. 5, 1883 (Barnard); vol. cvi. No. 2535, Aug. 31, 1883 (Hartwig); vol. cvii. No. 2550, Oct. 31, 1883 (Peters); *Month. Not.*, vol. xliii. p. 288, March 1883 (Brett).

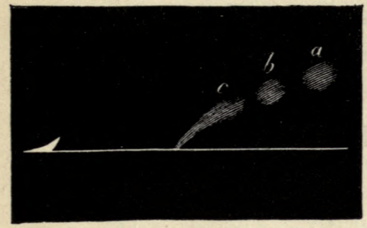
[n] *Month. Not.*, vol. xliv. p. 86, Jan. 1884.



THE GREAT COMET OF 1882: Oct. 19.

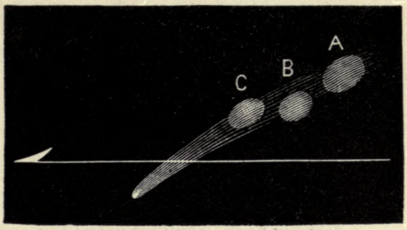
With reference to Holden's sketches dated October 13 and October 17, it may be remarked that 2 of the nuclei seen by Holden were seen by Cruls at Rio de Janeiro, at the intermediate date of October 15. Cruls found these nuclei to resemble

Fig. 227



Oct. 13. (*Holden.*)

Fig. 228.



Oct. 17. (*Holden.*)

THE COMPOUND NUCLEUS OF THE GREAT COMET OF 1882.

stars of the 7th and 8th magnitudes respectively, the distance between them being $6\frac{3}{4}''$. He was further led to regard the peculiar appearance of the tail as being really due to 2 tails, one superposed upon the other, each connected with a nucleus of its own, independent of the other.

Sawerthal's comet of 1888 exhibited on March 27 a triple nucleus not unlike that of the great comet of 1882 [o].

[o] Letter of M. Cruls in *Ast. Nach.*, vol. cxix. No. 2842, May 26, 1888.

CHAPTER IV.

CERTAIN STATISTICAL INFORMATION RELATING TO COMETS.

Dimensions of the Nuclei of Comets.—Of the Comæ.—Comets contract and expand on approaching to, and receding from, the Sun.—Exemplified by Encke's in 1838.*—Lengths of the Tails of Comets.—Dimensions of Cometary orbits.—Periods of Comets.—Number of Comets recorded.—Duration of visibility of Comets.—Unknown Comet found recorded on a photograph of the Eclipse of the Sun of May* 17, 1882.

THE following are the real diameters[a], in English miles, of the nuclei of some of the comets which have been satisfactorily measured[b] within the last hundred years:—

Examples of a Large Nucleus.

	Miles.
The Comet of 1845 (iii.)	8000
Donati's Comet, 1858	5600
The Comet of 1815	5300
The Comet of 1825 (iv.)	5100

Examples of a Small Nucleus.

	Miles.
The Comet of 1798 (i.)	28
The Comet of 1806	30
The Comet of 1798 (ii.)	125
The Comet of 1811 (i.)	428

[a] All the dimensions in miles in this chapter depend on the old value of the Sun's parallax. They need to be augmented by about $\frac{1}{30}$ to accommodate them to what is now regarded as the probable amount of the Sun's parallax. This has not however been done because all cometary measures are so uncertain that to give precise values in miles is affectation.

[b] This is in truth a very ambiguous expression, for when one considers the erratic motions of comets, the difficulty of ascribing definite boundaries to them, and the risk of error on the part of observers owing to peculiarities of telescope and weather, it will be readily understood how easy it is to make serious mistakes.

The dimensions of the *comæ*, or heads, of comets also vary greatly, thus:—

Examples of a Large Coma.	Miles.
The Comet of 1811 (i.) ...	1,125,000
Halley's Comet, 1835 ...	357,000
Encke's Comet, 1828 ...	312,000

Examples of a Small Coma.	Miles.
The Comet of 1847 (v.) ...	18,000
The Comet of 1847 (i.) ...	25,500
The Comet of 1849 (ii.) ...	51,000

It should be remarked that the real dimensions of comets are found to vary greatly at different periods of the same apparition, for there is no doubt that many of these bodies *contract* as they approach the Sun, and expand again as they recede from it—a fact first noticed by Kepler in the case of the great comet of 1611.

The following measurements of Encke's comet in 1838, when approaching the Sun, will illustrate this:—

Date.	Diameter.	Distance from ☉.
1838.	Miles.	
Oct. 9	281,000	1·42
,, 25	120,500	1·19
Nov. 6	79,000	1·00
,, 13	74,000	0·88
,, 16	63,000	0·83
,, 20	55,500	0·76
,, 23	38,500	0·71
,, 24	30,000	0·69
Dec. 12	6,600	0·39
,, 14	5,400	0·36
,, 16	4,250	0·35
,, 17	3,000	0·34

Another point of considerable interest in regard to the dimensions of comets is raised by the question, 'Do they waste away?' and it seems that the answer to this must be in the affirmative. It has been supposed that Halley's comet as described by contemporary writers 1500 or more years ago was possessed of a much larger and more brilliant tail than it has exhibited during the last 2 centuries. And probably there is some significance in the fact that none of the well-known short-period comets are noted for tails or ever exhibit more than what may be called apologies for tails.

The tails of comets, more especially of those visible to the naked eye, are often of stupendous length, as the following table will show:—

	Greatest Length.		Miles.
The Comet of 1744	24°	=	19,000,000
The Comet of 1860 (iii.)	15	=	22,000,000
The Comet of 1861 (ii.)	105	=	24,000,000
The Comet of 1769	97	=	40,000,000
The Comet of 1858 (vi.)	50	=	42,000,000
The Great Comet of 1618	104	=	50,000,000
The Comet of 1680	60	=	100,000,000
The Comet of 1811 (i.)	25	=	100,000,000
The Comet of 1811 (ii.)	37	=	130,000,000
The Comet of 1843 (i.)	65	=	200,000,000

Cometary orbits are usually of immense extent. Thus:—

1. *As to Perihelion Distance.*

Greatest Known.	Miles.	*Least Known.*	Miles.
The Comet of 1729 ...	383,800,000	The Comet of 1843 (i.) ...	538,000

2. *As to Aphelion Distance.*

Greatest Known.	Miles.	*Least Known.*	Miles.
The Comet of 1844 (ii.)	406,130,000,000	The Comet of Encke ...	388,550,000

We have already seen that the period of the shortest comet yet known is but little more than 3 years: this is in striking contrast to the periods exhibited in the following table, which are however so vast as to deserve little reliance:—

	Years.
The Comet of 1882 (i.)	400,000
The Comet of 1844 (ii.)	102,050
The Comet of 1780 (i.)	75,314
The Comet of 1877 (iii.)	28,000
The Comet of 1680	15,864
The Comet of 1847 (iii.)	13,918
The Comet of 1840 (ii.)	13,864

A significant fact with respect to the periods of the known periodical comets has already been mentioned [c], namely that there seems some disposition on the part of these comets to become associated with particular planets. It is not improbable that, as our knowledge becomes enlarged, some very interesting facts may come to light, which are at present hidden.

[c] See pp. 401, and 444, *ante*.

TABLE OF NUMBER OF COMETS RECORDED.

Period.	Comets Observed.	Orbits Calculated.	Comets Identified.
Before A.D.	79	4	1
Century 0—100	22	1	1
101—200	22	2	1
201—300	39	3	2
301—400	22	0	1
401—500	19	1	1
501—600	25	4	1
601—700	29	0	2
701—800	17	2	1
801—900	41	1	0
901—1000	30	2	3
1001—1100	37	4	2
1101—1200	28	0	1
1201—1300	29	3	3
1301—1400	34	7	3
1401—1500	43	12	1
1501—1600	39	13	4
1601—1700	32	20	5
1701—1800	72	64	8
1801—1888 (December)	270	249	68
	929	392	109

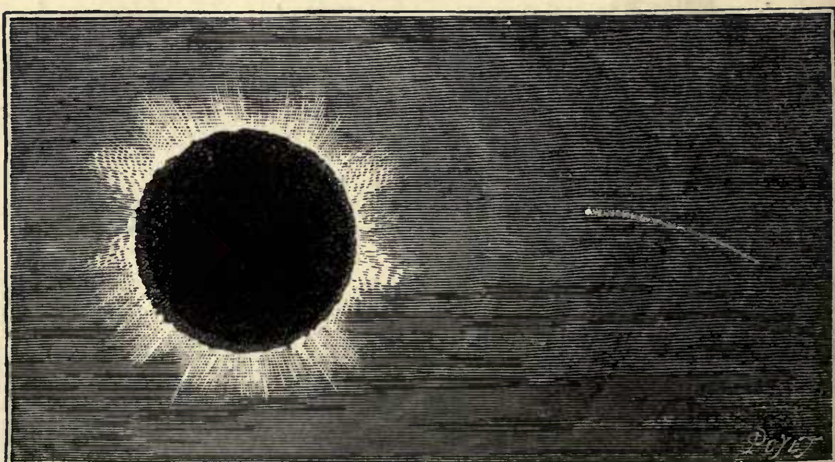
From the earliest period up to the present time, the number of comets of which there is any trustworthy record is somewhat over 900; but as it is only within the last 100 years that optical assistance has been made generally available in a systematic search for them, the real number of those that have appeared is probably not less than several thousands, especially when we consider that there have doubtless been many, visible only in the Southern hemisphere.

Comets remain visible for periods varying from a few days to more than a year, but the most usual time is 2 or 3 months. Much depends on the apparent position of the comet with respect to the Earth and the Sun, and much on its own intrinsic lustre. Among the comets which remained longest in sight, are the following:—

	Months.
The Comet of 1811 (i.)	17
The Comet of 1825 (iv.)	12
The Comet of 1861 (ii.)	12
The Comet of 1835 (iii.), (Halley's)	9½
The Comet of 1847 (iv.)	9½
The Comet of 1858 (vi.)	9
The Comet of 1882 (iii.)	9
The Comet of 1884 (i.)	9

There are some few comets which have only been seen on one or two occasions, unfavourable weather preventing more extended observation of them. Fig. 229 is a case in point. It represents a comet seen during the totality of the solar eclipse of 1882, which was never seen again, and as to whose history and fate we know nothing.

Fig. 229.



ECLIPSE OF THE SUN OF MAY 17, 1882, SHOWING AN UNKNOWN COMET. (*Ranyard.*)

CHAPTER V.

HISTORICAL NOTICES.

Opinions of the Ancients on the nature of Comets.—Superstitious notions associated with them.—Extracts from ancient Chronicles.—Pope Calixtus III. and the Comet of 1456.—*Extracts from the writings of English authors of the* 16*th and* 17*th centuries.—Napoleon and the Comet of* 1769.—*Supposed allusions in the Bible to Comets.—Conclusion.*

GOING back to the early ages of the world, we find that the Chaldæans considered comets to be permanent bodies analogous to planets, but revolving round the Sun in orbits so much more extensive, that they were therefore only visible when near the Earth. This opinion, which, by the by, is the earliest hint that we have of the existence of periodical comets, was also held by philosophers of the Pythagorean school. Yet Aristotle, who records this, insists that comets are merely mundane exhalations, carried up into the atmosphere, and there ignited.

Anaxagoras, Apollonius, Democritus, and Zeno considered that these bodies were aggregations of many small planets.

It is a somewhat remarkable fact, that Ptolemy, so celebrated for his varied astronomical attainments, should nowhere have made any mention of comets; his omission is, however, atoned for by Pliny, who seems to have paid much attention to them. He enumerates 12 kinds, each class receiving its name from some physical peculiarity of the objects belonging to it.

Seneca considered that comets must be above [*i.e.* beyond] the Moon, and he judged from their rising and setting, that they had something in common with the stars.

Paracelsus gravely insisted that comets were celestial messengers, sent to foretell good or bad events—an idea which, even in the present day, has by no means died out. The ancient Romans did not trouble themselves much about astral phenomena; they nevertheless looked upon the comet of 43 B.C. as a celestial chariot carrying away the soul of Julius Cæsar, who had been assassinated shortly before it made its appearance.

In an ancient Norman Chronicle there occurs a curious exposition of the divine right of William I. to invade England:—"How a star with 3 long tails appeared in the sky; how the learned declared that stars only appeared when a kingdom wanted a king, and how the said star was called a comette." Another old chronicler, speaking of the year 1060, says:—"Soon after [the death of Henry, King of France, by poison], a comet denoting, as they say, change in kingdoms—appeared, trailing its extended and fiery train along the sky. Wherefore, a certain monk of our monastery, by name Elmer, bowing down with terror at the sight of the brilliant star, wisely exclaimed, 'Thou art come! a matter of lamentation to many a mother art thou come; I have seen thee long since; but I now behold thee much more terrible, threatening to hurl destruction on this country[a].'"

The superstitious dread in which comets were held during the Middle Ages is well exemplified in the case of the comet of 1456 (Halley's). We find that the then Pope, Calixtus III., ordered the Church bells to be rung daily at noon, and extra *Ave Marias* to be repeated by everybody. Whilst the comet was still visible Hunniades, the Hungarian general, gained an advantage over Mahomet II., and compelled him to raise the siege of Belgrade, the remembrance of which the Pope preserved by ordering the Festival of the Transfiguration, the anniversary of which was kept a few days after the battle, to be observed throughout Christendom with additional solemnities. "Thus was established the custom, which still exists in Romish countries, of ringing the

[a] Will. Malmes., *De gestis Regum Angliæ*, lib. ii. cap. 225.

bells at noon; and perhaps it is from this circumstance that the well-known cakes made of sliced nuts and honey, sold at the Church-doors in Italy on Saints' days, are called *comete*[b]."

Leonard Digges says that "comets signify corruptions of the ayre. They are signs of Earthquakes, of warres, of chaungyng of kingdomes, great dearth of corne, yea a common death of man and beast[c]."

One John Gadbury says that "Experience is an eminent evidence, that a comet like a sword, portendeth war; and an hairy comet, or a comet with a beard, denoteth the death of kings." He also gives us a register of cometary announcements for upwards of 600 years, and adds in large Roman capitals, "as if God and nature intended by comets to ring the knells of princes, esteeming bells in Churches upon Earth not sacred enough for such illustrious and eminent performances."

Shakespeare speaks of—

> "Comets importing change of times and states
> Brandish your crystal tresses in the sky,
> And with them scourge the bad revolting stars
> That have consented unto Henry's death[d]."

Milton says:—

> "Satan stood
> Unterrified, and like a comet burned,
> That fires the length of Ophiuchus huge
> In th' Arctic sky, and from its horrid hair
> Shakes pestilence and war[e]."

The last comet employed in an astrological character was that of 1769, which Napoleon I. looked upon as his protecting *génie*. Indeed, as late as 1808 Messier published a work on it, of which the title is given below[f].

During the visibility of Donati's comet in 1858, the question was mooted whether the Bible contained any reference to these

[b] Smyth, *Cycle*, vol. i. p. 231. A friend suggests a derivation which certainly appears much more rational; namely, *comèdere*, to eat.

[c] *Prognostication Euerlastinge*, 2nd ed., London, 1576, fol. 6.

[d] *Henry VI.*, First Part, Act I. Scene 1.

[e] *Paradise Lost*, Book II.

[f] *La Grande Comète qui a paru à la Naissance de Napoléon le Grand.*

objects: the following passages were adduced in support of the idea:—

1. In *Leviticus* xvii. 7 it is said, "They shall no more offer their sacrifices unto Seirim," or Shoirim, which is rendered in the Authorised Version "devils," and in other versions "goats." Maimonides states that the Sabian astrologers worshipped these *seirim*, which seems to confirm the idea that they were celestial bodies.

2. In *Isaiah* xiv. 12 we find, "How art thou fallen from heaven, O Lucifer, son of the morning! how art thou cut down to the ground, which didst weaken the nations! For thou hast said in thy heart, I will ascend into heaven, I will exalt my throne above the stars of God." In this passage a certain Hillel is said to have fallen from heaven; but it is unknown what Hillel means. Some interpreters derive the word from Hebrew verbs signifying to glory, boast, agitate, howl, &c. Hillel *may* therefore signify a comet, for it answers to the ideas of brightness, swift motion, and calamity.

3. In the *General Epistle of St. Jude*, verse 13, certain impious impostors are compared to "wandering stars, to whom is reserved the blackness of darkness for an æon [age]." In all probability the passage may be taken to refer to comets[g].

4. The last quotation which I make is from the *Revelation of St. John the Divine*, xii. 3:—"There appeared another wonder in heaven; and behold a great red dragon, ... and his tail drew the third part of the stars of heaven." Satan is here likened to a comet, because a comet resembles a dragon (or serpent) in form, and its tail frequently does compass or take hold of the stars.

These ideas are given for what they are worth, and that is probably not much.

[g] See Alford's *New Test. for English Readers.* In loco.

CHAPTER VI.

DETERMINATION OF THE ELEMENTS OF THE ORBIT OF A COMET BY A GRAPHICAL PROCESS[a].

SECTION 1. *Preliminary.*

THE first and most important step to be taken in applying the following graphical process for the investigation of the orbit of a comet consists in working out the projection of the orbit on the ecliptic, which involves finding such an inclination of the plane of the orbit and such position of the node as shall be at once consistent with the longitudes and latitudes reduced from the observations available, and shall also satisfy Kepler's law of equal (or proportional) areas being described round the Sun in equal (or proportional) times; and afterwards to compare the developed orbit with one of the varieties of Conic Sections with which it must necessarily be in accord. This in practice means finding the proper parabola, for leaving out of consideration a few well-known elliptical comets of comparatively short period, the curve, whether elliptical or hyperbolic, approximates almost always so closely to the parabola that, until observations have been multiplied and all corrections for parallax and aberration have been applied, it is useless to attempt to discriminate between them. Moreover, the graphical method is scarcely available to indicate the course of a comet from only a few days' observations.

Let a scale, divided into 100 parts, be made, on card or stout

[a] This chapter has been specially written for this work by Mr. F. C. Penrose, F.R.A.S., and is an extension of a paper contributed by him to the Royal Astronomical Society in 1881. (*Month. Not.*, vol. xlvi. p. 68. Dec. 1881.)

paper (as it may have to be bent round a curve), to represent the Sun's mean distance; and inasmuch as many tentative proportions will have to be tried, the slide rule will be found a valuable auxiliary; but as the standard lines which represent the longitudes of the different observations used should be laid down very accurately, and are found once for all, it is better in the transformations of R. A.'s and Declinations into Longitudes and Latitudes to use logarithms. The *Nautical Almanack* gives for every day at noon the Sun's longitude and distance from the Earth. Interpolating these for the times of each observation we shall obtain with sufficient accuracy (neglecting parallax) the relative places of the observer and the Sun. Let the plane of the paper represent the ecliptic and lay down very carefully these terrestial places, and through them draw straight lines in the directions of the longitudes of the comet, already supposed to have been worked out. These lines should be drawn in ink, that they may not be erased in rubbing out the trial pencil-lines which will have to be drawn between them. It will also be convenient to mark down at this stage some subdivisions of the longitude lines where the heights above the ecliptic are as the numbers 20, 30, 40, &c.; these points being given by the co-tangents to the latitude. These marks will of course be confined to those parts of the longitude lines where the projection seems likely to pass. Theoretically 3 observations suffice to determine the path of a comet, but for the graphical investigation 4 are much better.

If the conversions from the equator to the ecliptic are performed by calculation the following remarks may be found useful.

(1) In using the formula below and referring to Fig. 230 in which P represents the North Pole and E the North Pole of the ecliptic, and C being any place of the comet[b], it should be observed that when the comet's R. A. is between 12 hours and 24, the angle at P is acute; and in the formula:

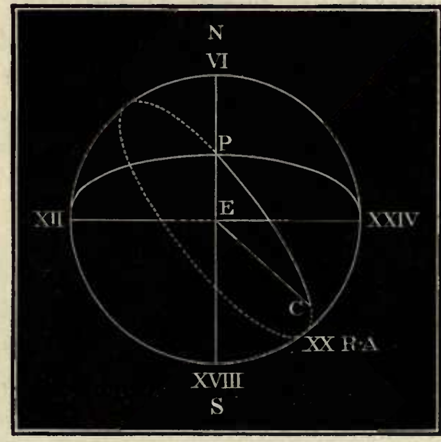
$$\cos EC = \cos PE \cos PC + \sin EP \sin PC \cos EPC$$

the latter value (cos E P C) will be positive, but for all other hours of R. A. it will be negative.

[b] Supposed in the diagram to be in R. A. 20^h and N. P. D. 84°.

(2) When the comet's R. A. is between 6 hours and 18, the supplement of the angle included between E P and E C must be deducted from 270°; to give the proper longitude, but for the other hours of R. A. the supplement of the said angle must be added to 270°.

Fig. 230.



RELATION OF THE EQUATOR TO THE ECLIPTIC.

The general formula referred to gives the latitude only. The longitude has to be derived from it and from the previous data by the formula:

$$\frac{\sin PEC}{\sin PC} = \frac{\sin EPC}{\sin EC};$$

and, as observed just above, the angle CES is to be added to or subtracted from 270° according to circumstances.

Also, before proceeding to the graphic work it is desirable to make a careful inspection of the longitude lines and the latitude numbers just described, as from the relation of these numbers to one another a sound hypothesis may usually be made of the course of the comet as it passes the different longitude lines by considering the connection between the heights above the ecliptic and their distance from the Earth. Without this help some doubt might at first arise in some cases as to which was the direction of the comet; that is, whether it was direct or retrograde. A few minutes devoted to this inspection may save much time in the end. In addition to the above, any information given in the recorded observations of variation in brightness or development of the comet's tail should be taken into account.

The first step now will be to take into consideration the lengths on the projection of the arcs traversed between the observations. These are not strictly proportional to the time-intervals either on the orbit or on the projection, but unless the observations record places very distant from one another the time-intervals may be used at the first start, and a table of these should be formed giving different numerical equivalents. For instance suppose the time-intervals were 7, 8, 9.

Form a table such as the following, viz.:

$$7 : 8 : 9,$$
$$8{\cdot}75 : 10 : 11{\cdot}25,$$
$$10{\cdot}5 : 12 : 13{\cdot}5;$$

which may be extended either by addition or interpolation as may be required when the circumstances of the case indicate which are likely to be the numbers most in request. The examples will show how these are applied, and in Section 5 Rules are given for correcting them for a second approximation.

The next step will be the adjustment of the areas and of the latitudes. A few preliminary remarks on these heads will be found useful.

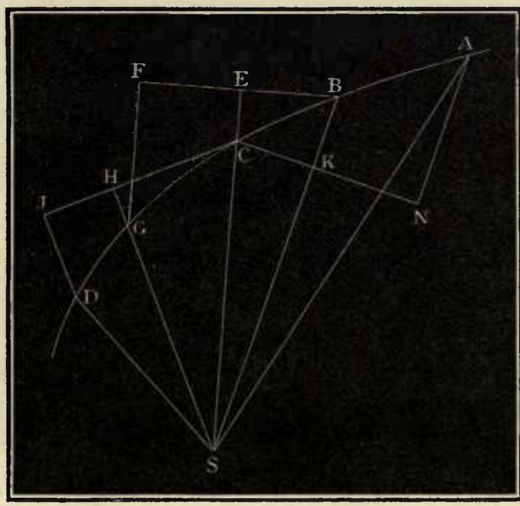
Section 2. *On the proportioning of the Areas in the different Segments of the Projection.*

Let the plane of the paper be that of the orbit, and let A B C D be the places under examination. If there is no great amount of deflection from the straight line as between A B and B C, the subtended areas are to each other nearly as the triangles formed by the chord with the radius vector; and if C N be a straight line drawn through K at right angles to S B, and if A N be parallel to S B, the area subtended by A B is to that subtended by B C very nearly as N K : K C; but if the question lies between such arcs as B C and C D, the difference in the areas inclosed between the chords and the arcs cannot be neglected in the comparison. In that case we may proceed thus:—Produce S C to E, make E F = E B, and following the previously described method cut off the arc C G, which approximately subtends the same area as B C, and by similar construction the remaining area subtended by G D can be measured.

Thus area B C S : area C D S : C H : C J.

Lines such as A N, F G, J D used in this construction may be conveniently called area-measurers or *pediometric* lines.

Fig. 231.



SCHEME FOR ADJUSTING THE SUBTENDED AREAS.

In the figure given above (Fig. 231) the curve of the orbit has been supposed, but the same holds good on the projection as respects the areas, although the arcs are not in simple proportion. A more exact rule for measuring the areas will be given in Sect. 5 (*post*), but the method just explained is sufficient for the purposes of approximation, and is very rapidly performed graphically.

Section 3. *The Latitudes and the Inclination of the Plane of the Orbit.*

In Fig. 232 let the plane of the paper represent the ecliptic, and let E be the position of the observer. Let E L be the direction of the comet's longitude, S ☊ the node, and p P p′ an arc of

Fig. 232.

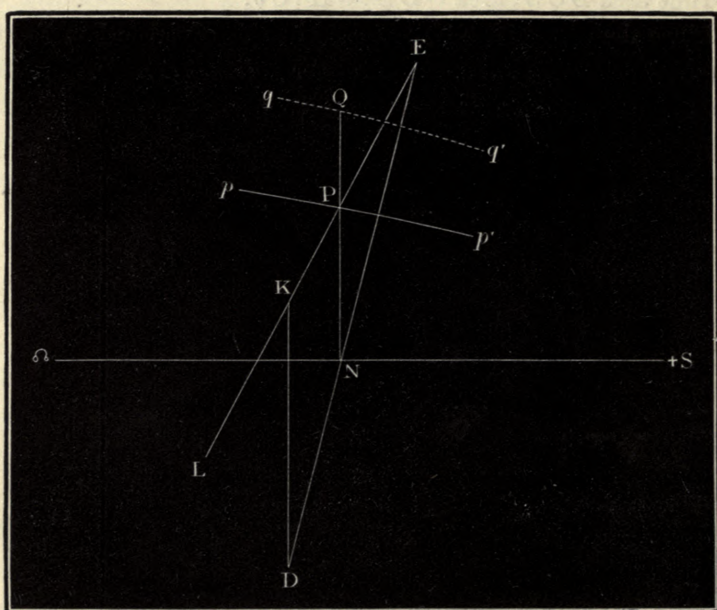


DIAGRAM FOR FINDING POINTS OF PROJECTION WHEN NODE AND INCLINATION ARE GIVEN.

the projection; and the dotted line q Q q′ an arc of the developed orbit: that is, the plane of the orbit is supposed to revolve on its node through the angle i until it coincides with the ecliptic, and let l be the observed latitude.

The height of the point P above the ecliptic can be measured either by P E tan l or P N tan i.

Let K be a point on E L, which for the sake of accuracy it is convenient to take at some distance from E. Through K draw K D perpendicular to S ☊, and make K D = K E tan l cot i. Join E D, and at the point N where it cuts the node draw a straight line perpendicular to the node. This line, if the angles and work are correct, will pass through P, because from similar triangles $\frac{NP}{PE} = \frac{KD}{KE}$, ∴ $NP = PE \cdot \frac{\tan l}{\tan i}$, or PE tan l = PN tan i, as above.

Thus with the node, latitude and inclination given, the point P is found by the intersection of E D with S ☊. K may be any point on E L, but it is convenient to take it at some definite value of cot l; for instance (our scale being the Earth's mean distance divided into 100 parts), K E tan l may be 100, 50, 25, &c. according to circumstances, as will be seen in the examples, *post.* When the projection has been found the developed orbit is easily obtained by making N Q = N P sec i.

The above method, which can be constructed very rapidly, offers a convenient plan for testing the accuracy of any given solution of the elements of the orbit of a comet, but for the purpose of the graphical working the process is as follows :—The direction of the node and the inclination of the orbit having been previously obtained, the method explained in this Section is used to bring the whole work together and to average the individual observations. After this has been done, and the different points so amended have been marked down, the work at this stage ought to be tried by the rule of the areas, and if it stands this test also, the small discrepancies which may still remain between the developement and the proper conic section (presumably a parabola) will be still further reduced by its comparison with that curve, and it will be seen what are the slight modifications which have to be made in the node or in the inclination, or in both, in order to reduce the outstanding errors. Whatever corrections are applied to these should be made by small instalments, and to each separately, and the effect noted down.

SECTION 4. *To find a Parabola having its Focus at S and which shall coincide with two Points of the Orbit.*

In Fig. 233 let Q and P be the two points; usually the extremities of the developement. With the centre Q and at the distance Q S, describe the arc S N F; and with the centre P and at the distance PS, describe the arc S M G. The straight line which

Fig. 233.

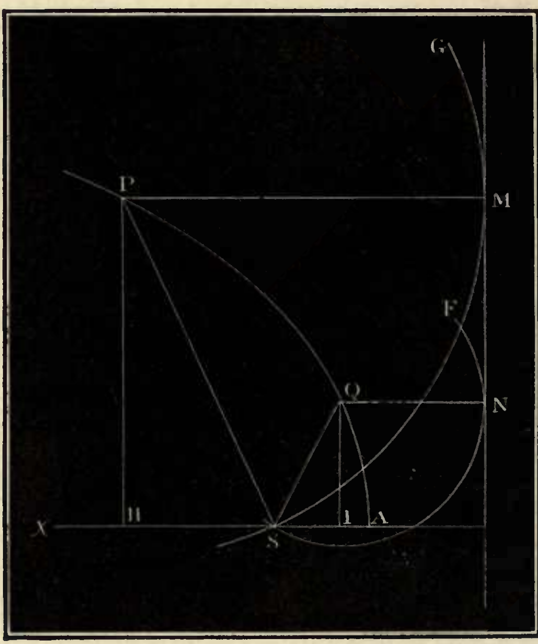


DIAGRAM FOR FINDING THE PERIHELION FROM GIVEN POINTS ON THE ORBIT.

is tangent to the two circles at M and N will be the directrix of the proper parabola, and from this all the other parts can be found. The curve when drawn may be conveniently applied on tracing-paper, keeping the focus on the place of the Sun and turning it about until it best fits all the points of the developement.

SECTION 5. *The Measurement of the Areas in a Parabola.*

Fig. 233 may also be used to illustrate the exact rule for the measurement of the areas in a parabola. Let A be the vertex, A S $= a$, and let P H and Q I be perpendiculars drawn from the principal axis A X.

If PSQ be the area of the space bounded between SP, SQ, and the curve, then

$$\frac{PH\,(AH+3\,AS)-QI\,(AI+3\,AS)}{6}=PSQ.$$

SECTION 6. *The Relations between the Time-intervals and the Longitude Lines.*

At the first opening of the enquiry, except the help given by the latitude numbers, as mentioned in Sect. 1, there is usually little to guide the student beyond the time-intervals and the longitude lines. It is important therefore to consider their relation to one another. Proportions founded on the time-intervals may generally be used as a useful first approximation unless the inclination of the orbit is very steep or there is a great change of direction in the path of the comet with respect to the node, between the different observations. As this may not unfrequently be the case, the remarks following should be taken into consideration.

In comparing the lengths of adjacent arcs in the orbit it can easily be shown that they are to each other inversely as the square root of the mean radius vector in each arc, and if the arcs are of limited extent are practically as the inverse square roots of the radii in the middle of each arc. This variation will of course affect the projection also, with which we primarily have to deal; but the arc in the projection also depends upon the general angle made with the node, which may frequently be taken without sensible error to be the angle which the chord of the arc makes with the node. Calling this angle, if measured on the orbit, a, or if on the projection, β, we should find that if s be a small arc of the projection corresponding to S on the orbit, $s : S :: \sqrt{1-\sin^2 a \sin^2 i} : 1$; or $s : S :: 1 : \sqrt{1+\tan^2 i \sin^2 \beta}$; the relation between a and β being $\tan\beta = \tan a \cos i$.

It will be seen that when a or β are small, and i not very great, the projection will have almost the same length as the original arc, and when these approach 90° the ratio of the projection to the original will be as 1 to sec i. Also it will be observed that when the inclination i is very steep it produces great influence on these proportions.

It follows from the above considerations that although the length of an arc traversed in a given time increases or diminishes as the comet approaches or recedes from the Sun, yet when we compare the adjacent arcs of the projection, this tendency may be

Fig. 234.

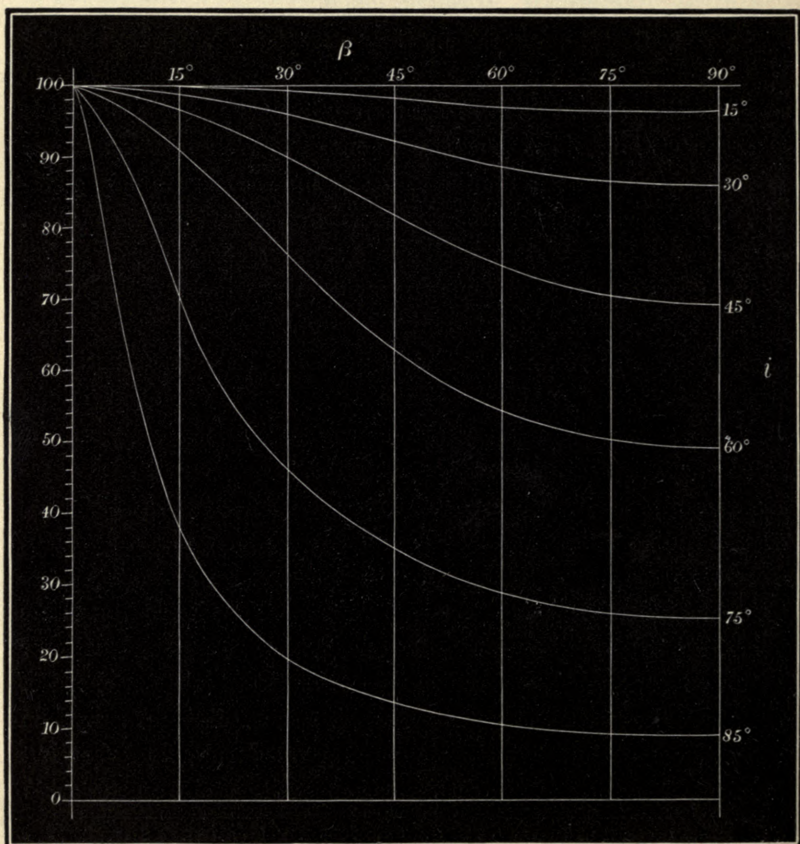


DIAGRAM FOR COMPARING ARCS.

greatly modified by the direction of its course with respect to the node. In the first approximations it is not desirable to try to calculate these effects minutely, although it will be useful to take some account of them when possible. But it may often be worth while to obtain a first approximation roughly, and from this to deduce the effect produced by the causes above referred to, and then to rub out the first pencillings and proceed afresh with an amended table of the intervals. The diagram here given (see opposite, Fig. 234), which has been calculated from the formula

$$\frac{s}{S} = \frac{1}{\sqrt{1 + \tan^2 i \sin^2 \beta}},$$

gives values of the length of a small arc of the projection compared with the corresponding arc of the orbit.

If the orbit has been developed and the angular direction of its course α ascertained, β is easily obtained from the relation $\tan \beta = \tan \alpha \cos i$. As an example of this diagram, if $\beta = 30^\circ$ and $i = 45^\circ$, it will be found by the scale that $s : S = 9 : 10$. Other values can be found by interpolation.

SECTION 7. *Checks available, derived from certain properties of Parabolic Orbits.*

When the elements of a comet have been approximately ascertained, a very useful check may be employed (confining our attention to parabolic orbits) from a consideration of the fact that the velocity of a comet in such an orbit at perihelion is to that of a planet moving in a circular orbit[c] at the same distance as $\sqrt{2}$ to 1.

The sine of the daily arc traversed by such a planet at Perihelion would be 1·7213 of our scale. In the comet at the same distance it would be 2·43302, and for any other distance this number must be divided by the square root of the distance.

It will often be useful to remember this principle at a preliminary stage, when a consideration of it may help to point out the distance at which the first approaches should be commenced.

SECTION 8. *Examples of the Graphical Process.*

The first example to be given is that of Schäberle's comet of 1881 (iv). Observations on 5 days will be considered. It is proposed to find the elements of the orbit from the first 4 and then to try them on the 5^{th} for a test and final correction.

[c] The motion of the earth in its orbit, although not quite circular, may without serious error be used in this comparison. It will require very little calculation, as it has necessarily been laid down graphically in the course of the work.

The observations reduced to longitude and latitude yielded the following apparent places:—

	G. M. T.	Longitude. ° ′ ″	Latitude. ° ′ ″	
Oxford	July 31·41	95 19 56	22 34 17	(1.)
,,	Aug. 4·42	99 2 24	25 8 9	(2.)
,,	,, 10·44	108 5 14	29 49 0	(3.)
,,	,, 19·53	137 33 22	36 7 0	(4.)
Marseilles	Sept. 2·33	199 18 0	17 22 0	(5.)

The Sun's places at these times with respect to the observer being—

	Longitude. ° ′ ″	Distance.
(1.)	128 44 43	101·50
(2.)	132 35 1	101·42
(3.)	138 25 17	101·35
(4.)	147 5 43	101·16
(5.)	160 26 6	100·84

The plane of the paper represents the ecliptic, S being the Sun's centre and S ♈ the line of the Equinoctial Node.

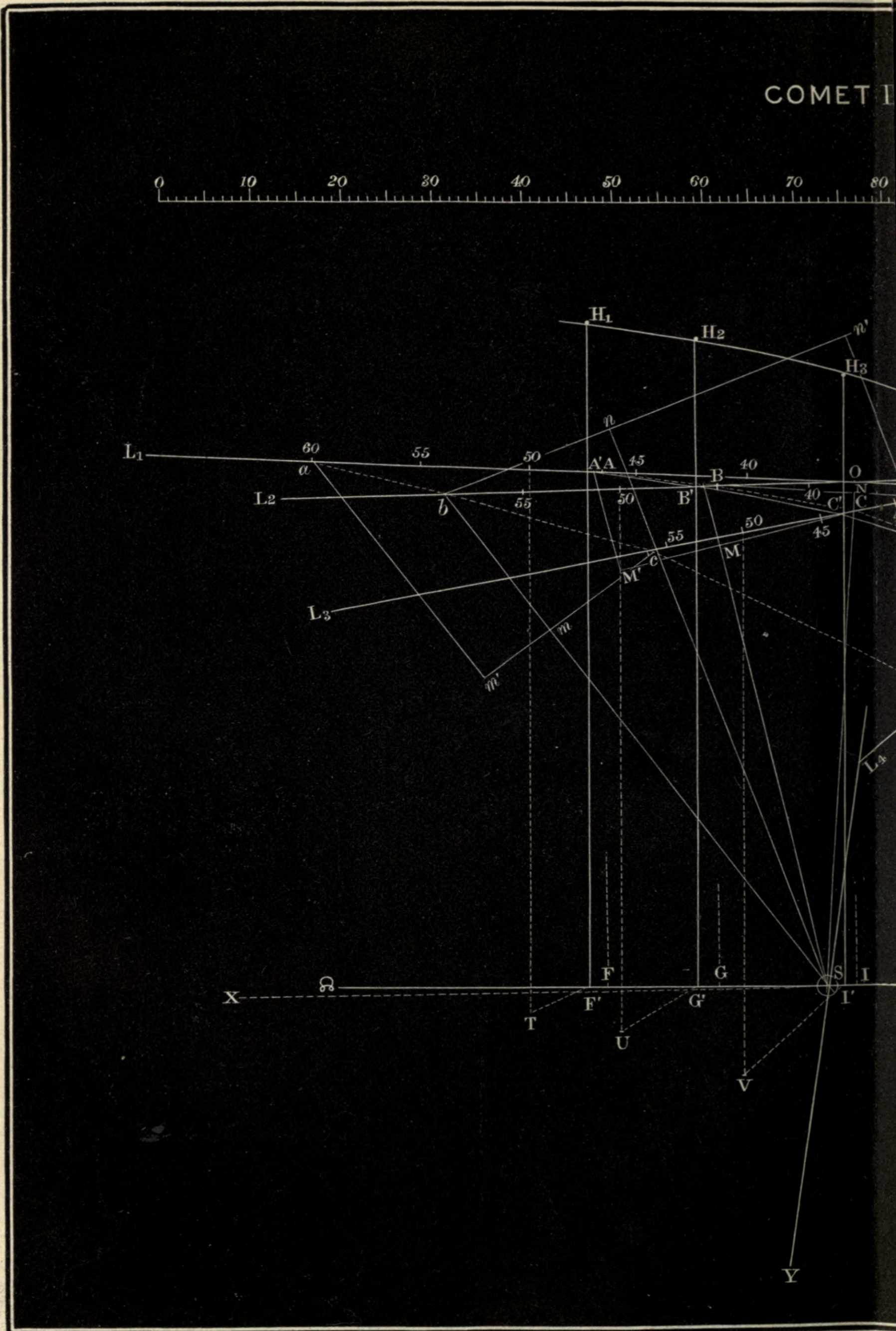
It is evident from the inspection of the latitude numbers (see Sect. 1) that during the first 4 observations the comet was passing from left to right, that is with retrograde movement, and approaching the Sun; and when first observed must have been a little beyond the point O where the first two longitude lines intersect. In this example we seem obliged at first to use the time-intervals as the only representatives of the lengths of the arcs, for at present no theory can yet be formed of modifications of their proportional length, as discussed in Section 5.

The table of time-intervals will be formed of such terms as:—

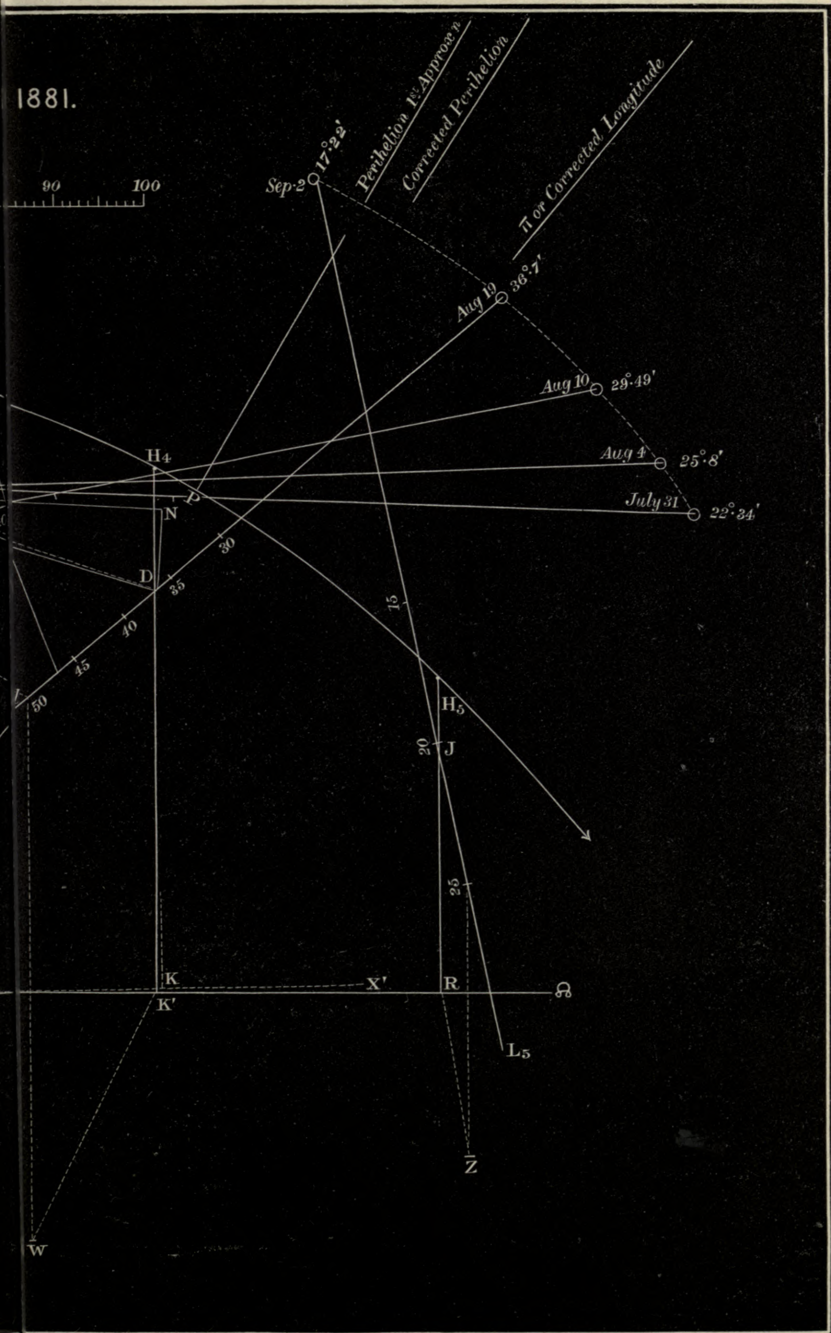
4·01	6·02	9·09
8	12	18·10
10	15	22·60
11·3	17	25·70
12·6	19	28·6
16	24	36·2

If we lay the scale of hundredths of the Sun's mean distance across the middle interval, and, allowing for moderate and continuous curvature, take in the adjacent spaces on each side, we

Fig. 235.



COMET I
0
10
20
30
40
50
60
70
80
H1
H2
H3
L1
L2
L3
L4
A'A
B
B'
O
N
C'
C
M
M'
S
I
I'
F
F'
G
G'
T
U
V
X
Y


1881.
90
100
Perihelion 1st Approx'n
Corrected Perihelion
π or Corrected Longitude
Sep·2
17°22'
Aug 19
36°·7'
Aug 10
29°·49'
Aug 4
25°·8'
July 31
22°·34'
H4
P
N
D
30
35
40
45
50
15
H5
20
J
25
K
X'
R
K'
☊
L5
Z
W

shall find that the two first terms of our table are out of the question. Nor will 15 by any sort of arrangement combine with 10 on one side and 22·6 on the other: but with 17 combined with 11·3 and 25·7 the case is different, and we may note down its points of coincidence, as at A, B, C, and D. It will be well however at this stage to proceed further and try another value, say 24, in the middle interval, and mark down also the places given on the four longitude lines, namely, *a*, *b*, *c*, *d*.

The reason for placing the scale at that particular obliquity to L_2 and L_3 so as to fall upon the points *a*, *b*, *c*, *d*, rather than in another way, nearer to or further from A, B, C and D, is the condition that the curvature of the projection must be fairly continuous. Nearer to A B C D it would have made *a b c d* too straight, or even convex to the Sun, and further from A B C D it would have been too abrupt. This consideration generally determines within very moderate limits the *direction* that these trial lines ought to take. The *distance* however will require a different discrimination, which we should now apply, namely, the area test. Join S B, S C, and draw the *pediometric* lines as explained in Section 2, namely, the offsets from M M′ which fall near A, and from N N′ which fall near D, thus confirming very nearly the points already chosen. When we apply a similar test to the other trial-curve by joining S *b*, S *c* &c., we find that the pediometrics *m m*′ and *n n*′ are quite discordant, especially *n n*′. Thus we may feel satisfied that to obey this test the projection cannot be far from a line passing through A B C and D. We now proceed to consider the latitudes and to obtain the inclination and the node. The heights above the ecliptic due to points on the longitude lines having been marked, show that in this case at the points A, B, C and D we have respectively 46·7, 45·7, 43·0 and 36·6. If these places were exact, the node could now be so drawn through S (similar to the node in Sect. 3) that the height of each of the above-named points, divided by the corresponding horizontal distance from the node, measured on the projection, would give the same value of tan i. Here it is nearly so, for we may so choose our base-lines passing through the Sun that the two outside points $\frac{46 \cdot 7}{FA}$ and $\frac{36 \cdot 6}{KD}$ give $39^\circ\ 30'$, whilst $\frac{45 \cdot 7}{GB}$ and $\frac{43}{CI}$ give $39^\circ\ 20'$; the mean being $39^\circ\ 25'$, and the approximate node X X′.

This approximate node might be found tentatively, but a better way is to join the two points under consideration, as A and D, and draw from A and D offsets equal to, or proportional to, the measure of their latitude number (or height above the ecliptic); join the extremities of the offsets; and produce as required to meet the produced line A D. The point of intersection will lie in the approximate node. That due to B and C will be found by similar construction. We are now in a position to use this approximate node and inclination to improve the figure by introducing a modification of the lengths of the arcs of the projection as explained in Section 6. If we draw perpendiculars to the node to the middle parts of the arcs of the projection, and develope them in the ratio of sec i : 1, we can obtain approximate places on the orbit and get a near value of the radius vector. These distances appear to be in AB, B C, and C D respectively about 75, 70 and 65, and on this account (as shown in Sect. 6) the spaces traversed in equal times in the three arcs would be to each other as $\frac{1}{865}$, $\frac{1}{837}$, $\frac{1}{807}$, but the angles which the chords of the arcs on the projection make with the node seem to be respectively $8^\circ\ 10'$, $10^\circ\ 45'$, and 18°.

Using the diagram of Section 6, and interpolating the values above measured for β in combination with $i = 40$, we obtain for the proportional lengths in the projection 0·99, 0·985, and 0·965.

The comparison of equal-time arcs therefore on these three sequents will be as :—

$$\frac{99}{865};\ \frac{985}{837};\ \frac{965}{807} = 1 \cdot 145;\ 1 \cdot 180;\ 1 \cdot 195.$$

The comparative arc intervals thus modified will have for their proportions 3·9; 6·02; 9·2; very nearly as 11; 17; 26.

In this example the corrections above found are small because the angle β of Section 6 is small, and i is not very large, but under certain circumstances they may become very significant. It must be borne in mind that these modifications affect only the *lengths* of the arcs, and in comparing the *areas* the true time-intervals must be used.

In making the adjustments it seems unnecessary to alter D, considering the favourable near coincidence of the pediometric line with that point, but the other points should be shifted to A′, B′ and C′, giving them latitude values of 47·1, 46·3, and 43·8 respectively.

The value of *i* which now results from the corrected numbers and the corresponding perpendiculars drawn to the node becomes 39° 45′, which we take for the measure of *i*, and the node takes the direction S ☊.

The next step is to use the method of Section 3, to establish points on the various longitude lines in accurate accordance with this node and inclination.

Choosing the latitude points 50, on each of the first four longitude lines, draw from A′ B′ C′ and D perpendiculars to S ☊, 60·1 in length, which will make $\frac{50.0}{60.1} = \tan i$. Draw straight lines from the extremities of these perpendiculars to their respective places of observation, and where they cut the node, as T F′, U G,′ &c., erect perpendiculars to their proper longitude lines and produce them upwards to form the developed figure by the method of Section 3. These points will be H_1 H_2 H_3 H_4. By that of Section 4 we can now obtain the parabola which will pass through H_1 and H_4. Let this be drawn on tracing-paper and applied as therein directed, and it will point out that, with the vertex at P, it will produce a very good coincidence with the four points of the developement, and will also satisfy very closely the rule of the areas.

We have obtained this parabola from 4 observations only. The fifth observation (that of September 2) may now be used to test its accuracy.

We shall find that if this observation be worked out in a manner similar to that of the others by obtaining the point Z due to latitude mark 25, and finishing the construction, that the point of its developement H_5 will fall at a distance of not more than 0·5 from the arc of the parabola produced, and that if the axis of the trial parabola 64 be reduced to 63·5 and the vertex or perihelion be turned towards H_5, a very small arc, about 2° 20′, there will be a very near coincidence indeed amongst all the points. After these corrections have been made the perihelion point measures along the curve 8·2 of the scale beyond the point due to Aug. 19·53, a distance traversable in about 2·70 days.

This gives the date of the perihelion, August 22·23.

The longitude of this point is 328° 20′.

The longitude of the node is 97° 30′.

The elements of the orbit, stated in the usual way, are :—

T	Aug. 22·23
π	328° 20′
q	0·636
☊	97° 30′
i	39° 45′
μ	Retrograde.

Stechert's published elements of this comet are :—

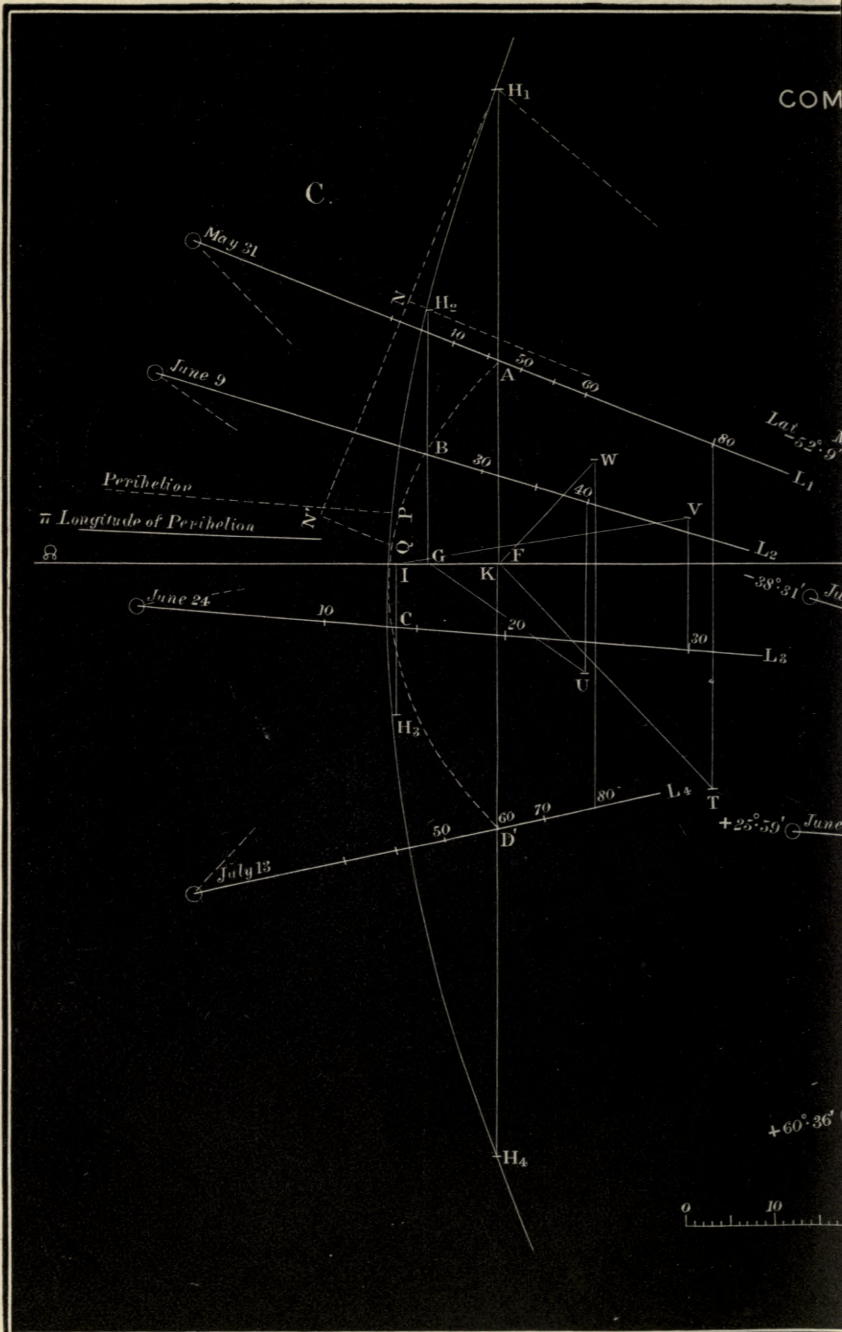
T	Aug. 22·29
π	334° 55′
q	0·633
☊	97° 2′
i	39° 46′
μ	Retrograde.

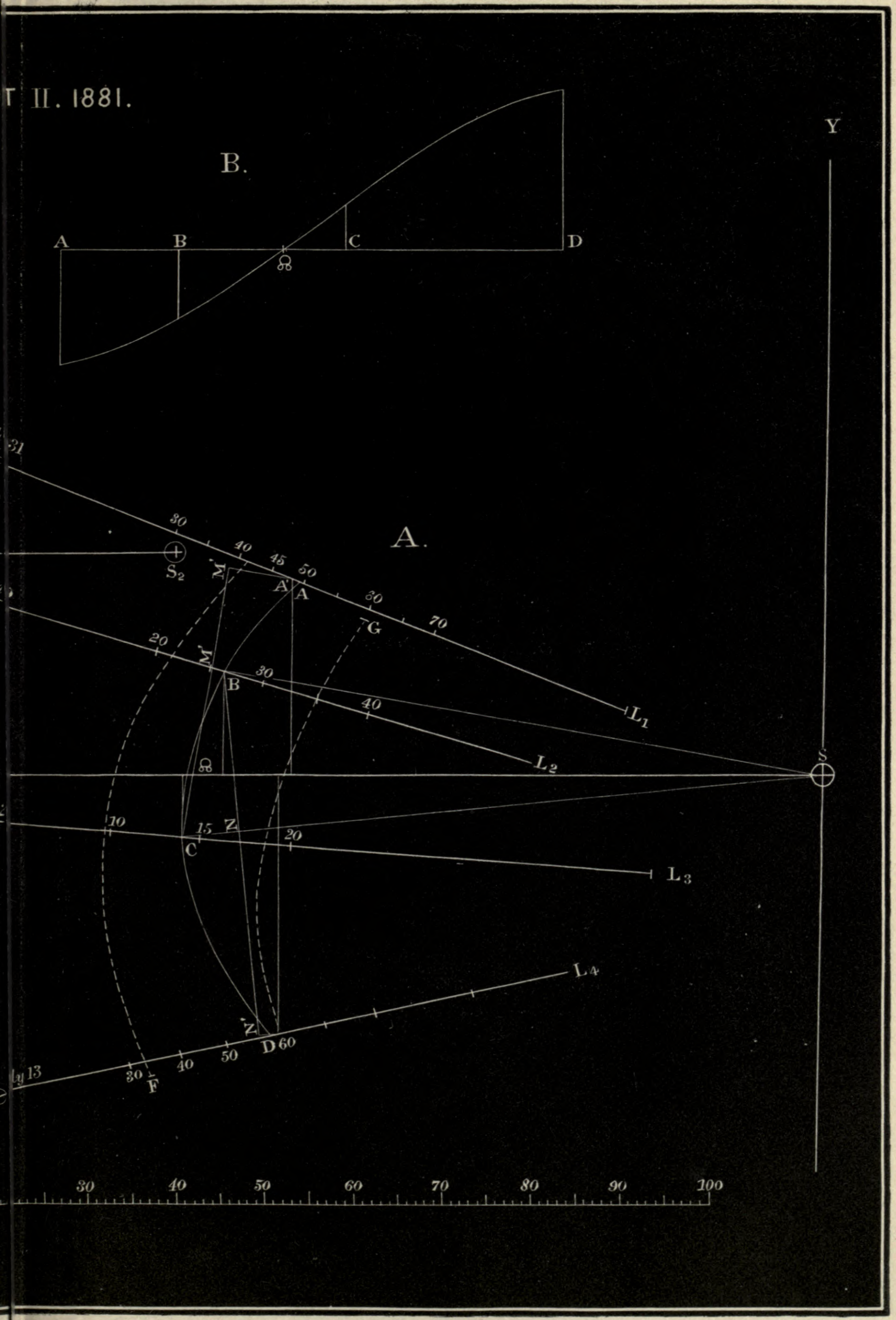
These last elements, if tried by the test of Section 3, do not in some particulars satisfy the geometrical conditions so well as those given above, found by the graphical process. In some of them there is very little difference.

The second example is that of Tebbutt's Comet of 1881 (iii). We will make use of 4 observations of apparent places reduced to the ecliptic :—

	G. M. T.	Longitude. ° ′ ″	Latitude. ° ′
1. Cape of Hope	May 31·21	69 38 6	−52 9
2. ,,	June 9·18	74 16 36	−38 31
3. Greenwich	June 24·48	86 19 6	+25 59
4. ,,	July 13·58	102 37 33	+60 36

Fig. 236.


COM
C.
May 31
June 9
June 24
July 13
Perihelion
π Longitude of Perihelion
H1
H2
H3
H4
N
N'
P
Q
I
G
K
F
A
B
C
D'
W
V
U
T
L1
L2
L3
L4
Lat
-52°.9'
-38°.31'
+25°.59'
+60°.36'
10
20
30
40
50
60
70
80
0
10


T II. 1881.
B.
A
B
C
D
☊
A.
Y
S
L1
L2
L3
L4
S2
M'
A'
A
G
M
B
C
Z
Z'
D
F
30
40
45
50
60
70
20
30
40
10
15
20
30
40
50
60
30
40
50
60
70
80
90
100

The Sun's places at these times, with respect to the observer, were :—

	Longitude. ° ′	Distance.
1.	70 18·9	101·43
2.	78 54·0	101·51
3.	93 29·6	101·66
4.	111 42·5	101·64

As in the previous example the plane of the paper represents the ecliptic, S being the Sun's centre, S Y in Pl. XXXV, Diagram A. is the line of the Equinoctial Node, and L_1 L_2 L_3 L_4 represent the different longitude lines with some of the heights above the ecliptic as derived from the latitude angles marked upon them.

The time-intervals in this case are :—

9·0 : 15·25 : 19·1.

It is clear however that at the time of the first and second observations the comet was approaching the Sun, and afterwards receding, and with a considerable change of angular direction. We may therefore fairly assume, although it would be premature to speak with exactness, that on the principles of Section 6 the first and third values in the three columns of time-intervals will be increased as compared with the middle column. Let us assume the proportions of the arc-intervals to be—

	9·8	15·25	19·7
or their equivalents	11·0	17·0	22·0
	12·3	19·0	24·6
	13·6	21·0	27·2

Placing 17 across the middle space and bending the scale a little so as to be slightly concave to the Sun, we find a fair agreement with 22 towards L_4, but the other interval is not well bridged, as it extends only to G, considerably short of L_1. The direction of the curve is from near the 60 mark on L_1 to the same figure on L_4.

With 21 on the central space, 13·6 may be found to agree fairly well with L_1, but 27·2 is considerably too long for the other space, and it overlaps it towards F, the direction being from near 41 on L_1 to 31 on L_4. It becomes therefore clear that a better result is to be looked for between these two trials. With

19 on the central space we can place both 12·3 on L_1 and 24·6 on L_4, the curve ranging from about 49 on L_1, 26 on L_2, 14·2 on L_3 to 58 on L_4; and we may now mark in the points A, B, C, D.

As in this example we have the opportunity of arriving very closely at the direction of the node, it will be convenient to obtain it at this stage. As the second observation was taken below the ecliptic and the third above, it follows that the node lies somewhere between these two. If, as in Diagram B. on Plate XXXV, the chords of the three arcs A B, B C, C D be taken as abscissæ, and ordinates given to the points A, B, C, and D proportional to the tangents of the latitude angles, we may construct a curve which will determine very nearly indeed the point ☊ where the latitude was zero, and we shall thus obtain the distance of the node either from C or B. Set off this distance C ☊ in the direction C B, and join S ☊; this will be the node. It will be at once apparent that neither of the two outside trial curves can satisfy the condition that $\tan i =$ the latitude number divided by that of the distance from the node, and it is unnecessary to apply the area test to them. We may therefore confine our attention to the points A, B, C, D.

On this curve the *pediometrics* M M′ and N N′ very nearly confirm the points already chosen. A, however, has to be shifted to A′ at 47·5, and D moved from 58 to 60. The combined heights of these two, 107·5, divided by the distance between them (perpendicular to the node), 51, representing $\tan i$, gives for this angle 64° 36′, whilst the angle derived from the two inner points B and C is 65° 8′; the mean 64° 42′.

At this point of the work it would usually be convenient to rub out the first trial pencil lines referred to in Section 1, and proceed by the method of the latitudes (see Section 3), but as that would destroy the previous work of this example, we proceed to Diagram C. on Plate XXXV. On L_1 at 80, L_2 at 40, L_3 at 30, and on L_4 at 80, ordinates are drawn, determined by the ratio $\tan i = \tan 64° 42'$. Draw T F, U G, V I, and W K as in the last example, and from the points F, G, I and K develope the orbit by making $F H_1 = F A \sec i$, &c.

By the method of Section 5, using H_1 and H_4, we determine the perihelion distance and other elements of the parabola which would pass through those two points. The distance so determined is 72·7. It will be seen by Diagram C. how nearly it coincides with H_2 and H_3. The vertex of the parabola (*i. e.* the perihelion) is at P; its longitude (π) measuring 268° 55′. The time T may be obtained thus:—By means of the pediometric line N N′ cut off Q, making the area subtended by $H_2 Q$ = that subtended by $H_1 H_2$, the time being 9 days. It is easy to measure the small arc R P as 1·21 day. T therefore becomes June $9{\cdot}18 + 9 - 1{\cdot}21$ = June 16·97. The elements of the orbit are now ascertained:—

T	June 16·97
π	268° 55′
q	0·727 [= log. 9·86153]
☊	270° 48′
i	64° 42′

The elements calculated by Mr. Hind were:—

T	June 16·457
π	265° 15′ 44″
q	0·7346 [= log. 9·8657]
☊	270° 57′ 46″
i	63° 28′ 46″

If we take the case of the comet dealt with in the last example it will appear that the space due to the parabolic orbit between the dates June 9 and June 24 should bear the proportion of about 1·671 : 1· (viz. $\sqrt{\frac{1\cdot016}{\cdot727}} \times \sqrt{2}$) to that traversed by the earth during the same period—a proportion which it will be found by measurement on the diagram has been very nearly obtained.

SECTION 9. *To form an ephemeris of a Comet.*

If it be desired to form an ephemeris from the elements of a comet's orbit the procedure graphically would be as follows:—

Taking the case of Example 1, namely given the perihelion distance 0·636, and the date of perihelion passage Aug. 22·23; let it be desired to find the comet's place in R. A. and Decl. for Sept. 2·33.

By dividing the normal value of daily motion at perihelion (Sect. 7) by $\sqrt{0\cdot636}$ we obtain in this case in terms of our scale 3·0518, and for the subtended area 97·049. This requires for 11·1 days an area of 1077·24.

The formula given in Section 5, namely, $A = \frac{y(x+3a)}{6}$, would suffice for finding the place on the orbit, but would require the solution of a cubic equation, and as that might be tedious, it would be more convenient to use the formula as a correction of a value otherwise obtained. By the *pediometric* method we should obtain $11\cdot1 \times 3\cdot0518 = 33\cdot875$ for the ordinate. This however would be somewhat too great, as the space inclosed between the chord and the arc is too large to be neglected. But the excess can be easily calculated.

From the equation to the parabola we readily obtain the quantity 4·5107 as the abscissa due to 33·875, and from the formula $A = \frac{y(x+3a)}{6}$ we obtain $A = 1105\cdot25$.

The area in excess, 28·01, is proportional to 0·29 of a day, so that instead of the place due to Sept. 2·33 we have that of Sept. 2·52, which will probably answer the purpose aimed at nearly as well: if not, an adjustment could be easily made.

If the point H_5 had been at a greater distance from the Perihelion, it would have been requisite to have approximated to it by stages by the pediometric method, as shown in Section 2, the place so obtained to be corrected by the formula used above.

The point H_5 on the orbit having been obtained, draw through it the straight line H R, perpendicular to the node, and find upon it the point J where $RJ = RH_5 \cos i$. Join $E_5 J$ and this will give the longitude of the required place. Also $\frac{RJ \tan i}{E_5 J} = \tan l$ gives the latitude.

The R. A. and Decl. may now either be computed or solved graphically.

CHAPTER VII.

A CATALOGUE OF ALL THE COMETS WHOSE ORBITS HAVE HITHERTO BEEN COMPUTED.

WHEN a new comet has been discovered, the first thing to be done is to obtain 3 observations of it, whereby the elements of the orbit may be computed. The computer will then examine a catalogue of comets to see if he can identify the newly-found stranger with any that have been before observed[a]. The value of a good catalogue is obvious; and therefore I have compiled as complete a one as possible.

In the preparation of the following list, care has been taken that only the most reliable orbits that were to be obtained should be inserted, the general rule being to prefer the one which was derived from the longest arc, other things being satisfactory. Among the authorities consulted may be mentioned *Pingré*, *Hussey*, *Olbers*, *Cooper*, *Hind*, *Arago*, *Galle*, and many others.

The Epoch of perihelion passage is expressed in Greenwich Mean Time, N.S., since 1582.

The Longitudes of Perihelion and of the Ascending Node are given for the respective epochs, but for any other epoch an allowance must be made for the effect of precession. This allowance is additive for subsequent dates and subtractive for previous ones, as follows: 1 year = 50″; 100 years = 1° 23′ 46″; 1000 years = 13° 56′ 50″.

The periods assigned in the column of "Duration of Visibility" are subject to much uncertainty, more especially in the case of the ancient comets.

[a] In the *Annuaire de l'Observatoire Royal de Bruxelles*, 1883, at p. 70, there will be found a catalogue of comets arranged in the order of the Inclinations.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° °	° °	°	
1	1	370 B. C.	Winter	150—210	270—330	above 30	very sm.
2	2	136	April 29	230	220	20	1·01
3	3	68	July	300—330	150—180	70	0·80
4	4	11	Oct. 8 19	280	28	10 ±	0·58
				° ′	° ′	° ′	
5	(4)	66 A. D.	Jan. 14 4	325 0	32 40	40 30	0·445
6	(4)	141	March 29 2	251 55	12 50	17 0	0·720
7	5	178	Sept. beg.	290	190	18	0·5
8	(4)	218	April 6	....	....	....	....
9	6	240	Nov. 9 23	271 0	189 0	44 0	0·372
10	(4)	295	April 1 ±	....	....	....	....
11	(4)	451	July 3 12	....	....	....	....
12	7	539	Oct. 20 14	313 30	58 or 238	10	0·341
13	8	565 ii.	July 11 18	84	158 45	60 30	0·775
14	9	568 ii.	Aug. 29 7	318 35	294 15	4 8	0·907
15	10	574	April 7 6	143 39	128 17	46 31	0·963
16	(4)	760	June 11	....	....	....	....
17	11	770	June 6 14	357 7	90 59	61 49	0·642
18	12	837 i.	Feb. 28 23	289 3	206 33	10—12	0·580
19	13	961	Dec. 30 3	268 3	350 35	79 33	0·552
20	(4)	989 ii.	Sept. 11 23	264	84	17	0·568
21	14	1006	March 22	304	38	17 30	0·583
22	(4)	1066	April 1 0	264 55	25 50	17 0	0·720
23	15	1092	Feb. 15 0	156 20	125 40	28 55	0·928
24	16	1097 i.	Sept. 21 21	332 30	207 30	73 30	0·738
25	17	1231	Jan. 30 7	134 48	13 30	6 5	0·948

1. It is said to have separated into two parts.

3. It had a short but brilliant tail.

4. An apparition of *Halley's comet* (?), mentioned by Dion Cassius as having been suspended over Rome previous to the death of Agrippa.

5. An apparition of *Halley's comet* (?). It had a tail 8° long.

6. An apparition of *Halley's comet*.

9. Elements somewhat doubtful. It had a tail 30° long.

11. Undoubtedly an apparition of *Halley's comet*.

12. It had a tail 10 feet long ! !

13. A mean orbit. It had a tail 10° long.

14. Elements very reliable. On Sept. 8 it had a tail 40° long.

15. Elements very uncertain.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	–	Pingré	....	Greek obs.	(?)
1·0	–	Peirce	....	Chinese obs.	5 weeks.
1·0	+	Peirce	68, July 23	Chinese obs.	5 weeks.
1·0	–	Hind	11, Aug. 26	Chinese obs.	9 weeks.
1·0	–	Hind	66, Jan. 31	Chinese obs.	7 weeks.
1·0	–	Hind	141, Mar. 27	Chinese obs.	4 weeks.
1·0	+	Hind			
1·0	..	Hind	218, April	....	6 weeks.
1·0	+	Burckhardt	240, Nov. 10	Chinese obs.	6 weeks.
..	..	Hind	295	....	7 weeks.
1·0	..	Laugier	451, May 17	Chinese obs.	13 weeks.
1·0	+	Burckhardt	539, Nov. 17	Chinese obs.	9 weeks.
1·0	–	Burckhardt	565, Aug. 4	Chinese obs.	15 weeks.
1·0	+	Laugier	568, Sept. 3	Chinese obs.	10 weeks.
1·0	+	Hind	574, May 2	Chinese obs.	13 weeks (?).
1·0	..	Laugier	760, May 16	Chinese obs.	8 weeks.
1·0	–	Laugier	770, May 26	Chinese obs.	10 weeks.
1·0	–	Pingré	837, Mar. 22	Chinese obs.	5 weeks.
1·0	–	Hind	962, Jan. 28	Chinese obs.	5 weeks.
1·0	–	Burckhardt	989, July 28	Chinese obs.	5 weeks.
1·0	–	Pingré	1006, April	European obs.	3 or 6 weeks.
1·0	–	Hind	1066, April 2	Chinese obs.	6 weeks or +.
1·0	+	Hind	1092, Jan. 8	Chinese obs.	17 weeks.
1·0	+	Burckhardt	1097, Sept. 30	Chinese obs.	4 weeks.
1·0	+	Pingré	1231, Feb. 6	Chinese obs.	4 weeks.

16. An apparition of *Halley's comet.*
17. It had a tail about 30° long.
18. Tolerably trustworthy. The maximum length of the tail was 80°, but it dwindled down to 30° in a fortnight.
20. Probably an apparition of *Halley's comet.* Mentioned by several Saxon writers.
21. These elements appear to have escaped the notice of recent cometographers, though given by Pingré; but has it been confounded with the following?
22. Possibly an apparition of *Halley's comet.* This is the famous object which created such universal dread throughout Europe in 1066. In England it was looked upon as a presage of the success of the Norman invasion.
23. Elements satisfactory.
24. A tail 50° long was seen in China, and much bifurcated.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
26	18	1264	July	15	23	272	30	175	30	30	25	0·430
27	19	1299	March	31	7	3	20	107	8	68	57	0·318
28	(4)	1301 i.	Oct.	23	23	312		138		13		0·640
29	20	1337 i.	June	15	1	2	20	93	1	40	28	0·828
30	21	1351	Nov.	25	23	69		Indeterminate.				1·0
31	22	1362 i.	March	11	4	219		249		21		0·456
32	23	1366	Oct.	21	11	48	4	217	25	27	37	0·979
33	(4)	1378	Nov.	8	18	299	31	47	17	17	56	0·583
34	24	1385	Oct.	16	6	101	47	268	31	52	15	0·774
35	25	1433	Nov.	7	18	267	1	96	20	76	0	0·492
36	26	1449	Dec.	9	9	264	26	261	18	24	20	0·327
37	(4)	1456	June	8	5	298	57	43	56	17	37	0·580
38	27	1457 iii.	Sept.	3	16	92	50	256	5	20	20	2·103
39	28	1462	Aug.	6	3	196		25		25		0·31
40	29	1468 ii.	Oct.	7	6	356	3	61	15	44	19	0·853
41	30	1472	Feb.	28	5	48	3	207	32	1	55	0·539
42	31	1490 {	Dec.	24	11	58	40	288	45	51	37	0·738
			Dec.	35	21	113		268		75		0·755
43	32	1499	Sept.	6	18	0		326	30	21		0·954
44	33	1500	May	17		290		310		75		1·4
45	34	1506	Sept.	3	15	250	37	132	50	45	1	0·386
46	(4)	1531	Aug.	24	21	301	39	49	25	17	56	0·5670
47	35	1532 {	Oct.	19	14	135	44	119	8	42	27	0·6125
			Oct.	19	22	111	7	80	27	32	36	0·5091
48	36	1533 {	June	14	21	217	40	299	19	28	14	0·3269
			June	16	19	104	12	125	44	35	49	0·2028

26. One of the grandest comets on record. Its tail is said to have been 100° long. Hoek has published several orbits all differing much from Pingré's.

27. Elements very doubtful.

28. Probably an apparition of *Halley's comet.*

29. A fine comet. The elements assigned by Halley, Pingré, and Hind differ somewhat from those here given.

30. Very uncertain. No latitudes given.

31. Uncertain. The tail was 20 *feet long*, and the head was *the size of a wine-glass!*

32. Very uncertain.

33. An apparition of *Halley's comet.*

34. Tolerably certain. The tail was 10° long.

37. An apparition of *Halley's comet.* It had a splendid tail, 60° long. At one time the head was round, and the size of a bull's eye, and the tail like that of a peacock!! (*Chinese Obs.*)

38. Only approximate. It had a tail 15° long.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Pingré	1264, July 14	Chinese & European	3 months.
1·0	−	Pingré	1299, Jan. 24	Chinese obs.	11 weeks.
1·0	−	Laugier	1301, Sept. 16	Chinese & European	6 weeks.
1·0	−	Laugier	1337, May	Chinese & European	3 or 4 months.
1·0	+	Burckhardt	1351, Nov. 24	Chinese obs.	1 week.
1·0	−	Burckhardt	1362, Mar. 5	Chinese obs.	5 weeks.
1·0	−	Hind	1366, Aug. 26	Chinese obs.	Several days.
1·0	−	Laugier	1378, Sept. 26	Chinese obs.	6 weeks.
1 0	−	Hind	1385, Oct. 23	Chinese obs.	(?)
1·0	−	Celoria	1433, Oct. 12	Chinese obs.	2 months.
1·0	+	Celoria	1450, Jan. 19	Chinese obs.	7 weeks.
0·96	−	Celoria	1456, May 29	European & Chinese	1 month.
1·0	+	Hind	1457, June	European obs.	3 months.
1·0	−	Hind	1462	Chinese obs.	
1·0	−	Laugier	1468, Sept.	European obs.	2 or 3 months.
1·0	−	Laugier	1471, Dec.	Regiomontanus	3 months.
1·0	+	Hind }	1491, Jan.	Chinese obs.	(?)
1·0	−	Peirce }			
1·0	+	Hind	1499	Chinese obs.	(?)
1·0	−	Hind	1500, April	European & Chinese	3 weeks or + .
1·0	−	Laugier	1506, July 31	Chinese obs.	2 weeks.
1·0	−	Halley	1531, Aug. 1 ±	P. Apian	5 weeks.
1·0	+	Méchain }	1532, Sept. 22	P. Apian	16 weeks.
1·0	+	Halley }			
1·0	+	Olbers }	1533, June	P. Apian	$2\frac{1}{2}$ months.
1·0	−	Douwes }			

40. Uncertain. It had a tail 30° long.

41. A celebrated comet. When at its least distance from the Earth (3,300,000 miles), on Jan. 21, it was quite visible in full daylight. It had a fine tail, which the Chinese say was *as long as a street!*

42. Uncertain.

43. In the middle of August this Comet seems to have approached very near to the Earth.—(Hind, MSS. *communicated.*)

44. Elements uncertain. It was *as large as a ball!* and had a tail from 3° to 5° long.

46. An apparition of *Halley's comet.* It had a tail 7° long.

47. It had a tail several degrees long. Olbers has computed an orbit which agrees well with Halley's, but Méchain's is considered the best.

48. According to Olbers, both these orbits will satisfy the observations, and it is as yet impossible to decide between them. It had a tail 15° long.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
49	(18)	1556	April	22	0	274	14	175	25	30	12	0·5049
50	37	1558	Aug.	10	12	329	49	332	36	73	29	0·5773
51	38	1577	Oct.	26	22	129	42	25	20	75	9	0·1775
52	39	1580	Nov.	28	12	108	26	19	6	64	33	0·6023
53	40	1582	May	6	16	245	23	231	7	61	27	0·2257
			May	6	10	256	15	229	18	60	47	0·1683
54	41	1585	Oct.	8	0	9	8	37	44	6	5	1·0948
55	42	1590	Feb.	8	0	217	57	165	37	29	29	0·5677
56	43	1593	July	18	13	176	19	164	15	87	58	0·0891
57	44	1596	July	25	5	270	54	330	20	51	58	0·5671
58	(4)	1607	Oct.	27	0	300	46	48	14	17	6	0·5841
59	45	1618 i.	Aug.	17	3	318	20	293	25	21	28	0·5129
60	46	— iii.	Nov.	8	8	3	5	75	44	37	11	0·3895
61	47	1652	Nov.	12	15	28	18	88	10	79	28	0·8475
62	(35 ?)	1661	Jan.	26	21	115	16	81	54	33	0	0·4427
63	48	1664	Dec.	4	12	130	33	81	15	21	18	1·0255
64	49	1665	April	24	5	71	54	228	2	76	5	0·1064
65	50	1668	Feb.	24	18	40	9	193	26	27	7	0·2511
			Feb.	28	19	277	2	357	17	35	58	0·0047
66	51	1672	March	1	8	46	59	297	30	83	22	0·6974
67	52	1677	May	6	0	137	37	236	49	79	3	0·2805
68	53	1678	Aug.	18	7	322	47	163	20	2	52	1·1453

49. A very fine comet, which was expected to return in 1860.

50. Hoek gives: PP. = Sept. 13; π 215°; ☊ 335°; ι 69°: $q = 0{\cdot}280$.

51. It had a tail 22° long. This comet formed the subject of the observations of Tycho Brahe for the detection of parallax.

52. Elements approximate. Observed also by Tycho Brahe.

53. Very uncertain. It had a faint tail 3° long, which resembled a piece of silk!!

54. This orbit was computed some years ago, to see whether the comet of 1844 (ii) was identical with this one.

55. It had a tail 7° long.

56. It had a tail 4½° long.

57. Discovered also by Tycho Brahe.

58. An apparition of *Halley's comet.* It had a tail 7° long.

59. Somewhat uncertain. Seen at Lintz, Aug. 27, and by Kepler, Sept. 1.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Hind	1556, Feb. 28	P. Fabricius	10 weeks.
1·0	–	Olbers	1558, July 14	Landgrave of Hesse	6 weeks.
1·0	–	Woldstedt	1577, Nov. 1	In Peru	12 weeks.
1·0	+	Schjellerup	1580, Oct. 2	Mœstlin	10 weeks.
1·0	–	Pingré	1582, May 12	Tycho Brahe	3 weeks.
1·0	–	D'Arrest			
1·0	+	C. A. Peters and Sawitsch	1585, Oct. 19	Tycho Brahe & Rothmann	4 weeks.
1·0	–	Hind	1590, Mar. 5	Tycho Brahe	3 weeks.
1·0	+	La Caille	1593, July 20	De Rissen	6 weeks.
1·0	–	Hind	1596, July 11	Mœstlin	5 weeks.
0·96708	–	Lehmann	1607, Sept. 11	Kepler	9 weeks.
1·0	+	Pingré	1618, Aug. 25	At Caschau	4 weeks.
1·0	+	Bessel	— Nov. 30	Many observers.	7 weeks.
1·0	+	Halley	1652, Dec. 20	Hevelius	3 weeks.
1·0	+	Méchain	1661, Feb. 3	Hevelius	5 weeks.
1·0	–	Lindelof	1664, Nov. 17	In Spain	17 weeks.
1·0	–	Halley	1665, Mar. 27	At Aix	4 weeks.
1·0	+	Henderson }	1668, Mar. 5	Gottignies, etc.	3 weeks.
1·0	–	Henderson }			
1·0	+	Halley	1672, Mar. 2	Hevelius	7 weeks.
1·0	–	Halley	1677, April 27	Hevelius	12 days.
0·62697	+	Le Verrier	1678, Sept. 11	La Hire	4 weeks.

60. A splendid comet; it had a tail, according to Longomontanus, 104° long, and of a reddish hue. Said to have been visible in the daytime.

61. Elements only approximate.

62. By some supposed to be identical with the comet of 1532; it was not re-observed, however, as was anticipated, about 1791.

63. It had a tail from 6° to 10° long.

64. It had a tail 25° long.

65. Seen chiefly in the southern hemisphere; both orbits satisfy the observations, and it is impossible to say which is the correct one.

66. It had a tail about 1° long.

67. It had a tail about 6° long.

68. Elements only approximate.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
69	54	1680	Dec.	17	23	262	49	272	9	60	40	0·0062
70	(4)	1682	Sept.	14	19	301	55	51	11	17	44	0·5829
71	55	1683	July	13	2	85	35	173	24	83	13	0·5595
72	56	1684	June	8	10	238	52	268	15	65	48	0·9601
73	57	1686	Sept.	16	14	77	0	350	34	31	21	0·3250
74	58	1689	Nov.	29	4	269	41	90	25	59	4	0·0189
75	59	1695	Nov.	9	16	60		216		22		0·8435
76	60	1698	Oct.	18	16	270	51	267	44	11	46	0·6912
77	61	1699 i.	Jan.	13	8	212	31	321	45	69	20	0·7440
78	62	1701	Oct.	17	9	133	41	298	41	41	39	0·5926
79	63	1702 ii.	March	13	14	138	46	188	59	4	24	0·6468
80	64	1706	Jan.	30	4	72	29	13	11	55	14	0·4258
81	65	1707	Dec.	11	23	79	54	52	46	88	36	0·8597
82	66	1718	Jan.	14	21	121	39	127	55	31	8	1·0254
83	67	1723	Sept.	27	15	42	52	14	14	50	0	0·9987
84	68	1729	June	13	6	320	31	310	38	77	5	4·0435
85	69	1737 i.	Jan.	30	8	325	55	226	22	18	20	0·2228
86	70	— ii.	June	2	5	261	58	132	5	61	52	0·8349
87	71	1739	June	17	10	102	38	207	25	55	42	0·6735
88	72	1742 i.	Feb.	8	4	217	35	185	38	66	59	0·7656
89	73	1743 i.	Jan.	8	4	93	19	86	54	1	53	0·8615
90	74	— ii.	Sept.	20	21	247	0	6	2	45	37	0·5229
91	75	1744	March	1	8	197	12	45	45	47	8	0·2220

69. A splendid comet, whose tail ultimately attained a length of from 70° to 90°. Halley conjectured that this was a return of the comet of 1106, 531 A.D., and 44 B.C., but this has since been shewn to be unlikely. The orbit here given supposes a period of 8814 years; this, however, is subject to much uncertainty, inasmuch as the observations might possibly be satisfied by an 805 years' ellipse, or even by a hyperbolic orbit.

70. An apparition of *Halley's comet*. It had a tail from 12° to 16° long.

71. It had a tail varying from 2° to 4°.

73. Its nucleus was as bright as a 1st-magnitude star, and it had a tail 18° long.

74. Observed very roughly in the East Indies. It had a tail 60° long. Pingré makes the ☊ = 323° 45′.

75. Observed still more imperfectly than the last in the southern hemisphere. It had a tail 18° long.

76. Uncertain.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·99998	+	Encke	1680, Nov. 14	G. Kirch	18 weeks.
0·96792	—	Rosenberger	1682, Aug. 15	Flamsteed	5 weeks.
1·0	—	Plummer	1683, July 23	Flamsteed	6 weeks.
1·0	+	Halley	1684, July 1	Bianchini	2 weeks.
1·0	+	Halley	1686, Aug.	In India	1 month.
1·0	—	Vogel	1689, Dec. 10	Richaud	2 weeks.
1·0	+	Burckhardt	1695, Oct. 28	Jacob	3 weeks.
1·0	—	Halley	1698, Sept. 2	La Hire	4 weeks.
1·0	—	La Caille	1699, Feb. 17	Fontenay	2 weeks.
1·0	—	Burckhardt	1701, Oct. 28	Pallu	1 week.
1·0	+	Burckhardt	1702, April 20	Bianchini	2 weeks.
1·0	+	La Caille	1706, Mar. 18	J. D. Cassini	4 weeks.
1·0	+	La Caille	1707, Nov. 25	Manfredi	8 weeks.
1·0	—	Argelander	1718, Jan. 18	C. Kirch	3 weeks.
1·0	—	Spörer	1723, Oct. 9	Uncertain	9 weeks.
1·00503	+	Burckhardt	1729, July 31	Sarabat	25 weeks.
1·0	+	Bradley	1737, Feb. 6	In Jamaica	4 weeks.
1·0	+	Hind	— Feb.	At Pekin	(?)
1·0	—	La Caille	1739, May 28	Zanotti	11 weeks.
1·0	—	La Caille	1742, Feb. 5	Cape of G. Hope	13 weeks.
0·72130	+	Clausen	1743, Feb. 10	Grischau	2 weeks.
1·0	—	D'Arrest	— Aug. 18	Klinkenberg	4 weeks.
1·0	+	Betts	— Dec. 9	Klinkenberg	4 months (?)

78. Observed also by Thomas at Pekin.
79. Very roughly observed; visible to the naked eye.
81. Discovered by J. D. Cassini, Nov. 29.
83. It was seen in Europe, with a faint tail 1° long.
84. Scarcely perceptible to the naked eye. The orbit is a hyperbolic one, and remarkable for its enormous perihelion distance, the greatest known.
86. Elements only approximate.
88. Visible to the naked eye, with a tail 6° or 8° long.
89. Very imperfectly observed. An elliptic orbit; period assigned, 5·436 years.
90. Very uncertain. Visible to the naked eye.
91. The finest comet of the 18th century. On Feb. 15 it had a bifid tail, the eastern portion being 7° long, and the western 24°. Visible in a telescope in the daytime. Euler has calculated an elliptic orbit, to which he assigns a period of 122,683 years!! The statement of this comet having had six tails (at one time disbelieved) has been confirmed by the testimony of De Lisle discovered by Winnecke.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° ′	° ′	° ′	
92	(17?)	1746	Feb. 15 0	140 0	335 0	6 0	0·95
93	76	1747	March 3 7	277 2	147 18	79 6	2·1985
94	77	1748 i.	April 28 18	215 23	232 51	85 28	0·8404
95	78	— ii.	June 18 21	278 47	33 8	67 3	0·6253
96	79	1757	Oct. 21 7	122 58	214 12	12 50	0·3375
97	80	1758	June 11 3	267 38	230 50	68 19	0·2153
98	(4)	1759 i.	March 12 13	303 10	53 50	17 36	0·5845
99	81	— ii.	Nov. 27 2	53 24	139 39	78 59	0·7985
100	82	— iii.	Dec. 16 21	138 24	79 50	4 51	0·9659
101	83	1762	May 28 8	104 2	348 33	85 38	1·0090
102	84	1763	Nov. 1 20	84 58	356 24	72 31	0·4982
103	85	1764	Feb. 12 13	15 14	120 4	52 53	0·5552
104	86	1766 i.	Feb. 17 8	143 15	244 10	40 50	0·5053
105	87	— ii.	April 26 23	251 13	74 11	8 1	0·3989
106	88	1769	Oct. 7 14	144 11	175 3	40 45	0·1227
107	89	1770 i.	Aug. 13 12	356 16	131 59	1 34	0·6743
108	90	— ii.	Nov. 22 5	208 22	108 42	31 25	0·5282
109	91	1771	April 19 5	104 3	27 51	11 15	0·9034
110	92	1772	Feb. 19 2	110 14	254 0	18 17	1·0136
111	93	1773	Sept. 5 14	75 10	121 5	61 14	1·1268
112	94	1774	Aug. 15 19	317 27	180 44	83 20	1·4328
113	95	1779	Jan. 4 2	87 14	25 4	32 30	0·7131
114	96	1780 i.	Sept. 30 22	246 35	123 41	54 23	0·0963

92. Elements uncertain, but they strongly resemble those of the comet of 1231. It passed very near the Earth.

93. Observed only during 1746.

94. Discovered by J. D. Maraldi, April 30. Visible to the naked eye, with a tail 2° long.

95. Very uncertain.

96. Elements tolerably reliable. It had a small tail.

98. The first *predicted* apparition of *Halley's comet.* On May 5 its tail was 47° long.

99. Visible to the naked eye, with a tail 5° long. Elements resemble those of the comet of 1449.

100. This comet came near the Earth, and moved with great rapidity; it had a tail 4° long.

101. It had a small tail.

102. An elliptic orbit; period assigned, 7334 years. Lexell makes it 1137 years.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Hind	1746, Feb. 2	Kindermans	4 weeks.
1·0	−	La Caille	— Aug. 13	Chésaux	15 weeks.
1·0	−	Le Monnier	1748, April 26	At Pekin	9 weeks.
1·0	+	Bessel	— May 19	Klinkenberg	4 days.
1·0	+	Bradley	1757, Sept. 11	Gartner	5 weeks.
1·0	+	Pingré	1758, May 26	La Nux	5 months.
0·96768	−	Rosenberger	— Dec. 25	Palitzch	5 months.
1·0	+	La Caille	1760, Jan. 25	Messier	8 weeks.
1·0	−	La Caille	— Jan. 7	At Lisbon	14 weeks.
1·0	+	Burckhardt	1762, May 17	Klinkenberg	6 weeks.
0·99868	+	Burckhardt	1763, Sept. 28	Messier	8 weeks.
1·0	−	Pingré	1764, Jan. 3	Messier	6 weeks.
1·0	−	Pingré	1766, March 8	Messier	9 weeks.
0·8640	+	Burckhardt	— April 1	Helfenzrieda	6 weeks.
0·99924	+	Bessel	1769, Aug. 8	Messier	16 weeks.
0·78683	+	Le Verrier	1770, June 14	Messier	15 weeks.
1·0	−	Pingré	1771, Jan. 10	La Nux	8 days.
1·00936	+	Encke	— April 1	Messier	15 weeks.
0·90314	+	Bessel	1772, Mar. 8	Montaigne	3 weeks.
1·0	+	Burckhardt	1773, Oct. 12	Messier	27 weeks.
1·02829	+	Burckhardt	1774, Aug. 11	Montaigne	11 weeks.
1·0	+	Zach	1779, Jan. 6	Bode	19 weeks.
0·99994	−	Clüver	1780, Oct. 26	Messier	5 weeks.

103. Visible to the naked eye, with a tail $2\frac{1}{2}°$ long.

105. Discovered by Messier, April 8. An elliptic orbit; period assigned, 5·025 years. Visible to the naked eye, with a tail 3° or 4° long.

106. Visible to the naked eye, with a tail from 60° to 80° long. Bessel assigns 2090 years as the most likely period of revolution. He has shewn that an error of 5″ either may increase the period to 2673 years or diminish it to 1692 years.

107. The celebrated *Lexell's comet*. The diameter of the head, July 1, was $2\frac{1}{3}°$. It had also a small tail, and approached within 1,400,000 miles of the Earth.

108. It had a faint tail, 5° long.

109. The orbit of this comet has been found hyperbolic. It had a tale about 2° long. Recent calculations by Kreuz negative the hyperbola (*A. N.*, 2469).

110. The first recorded apparition of *Biela's comet*.

111. Just perceptible to the naked eye.

113. Discovered by Messier, Jan. 18.

114. An elliptic orbit; period assigned, 75,314 years.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° ′	° ′	° ′	
115	97	1780 ii.	Nov. 28 20	246 52	141 1	72 3	0·5152
116	98	1781 i.	July 7 4	239 11	83 0	81 43	0·7758
117	99	— ii.	Nov. 29 12	16 3	77 22	27 13	0·9610
118	100	1783 i.	Nov. 19 13	49 31	55 12	47 43	1·4953
119	101	1784 i.	Jan. 21 4	80 44	56 49	51 9	0·7078
120	102	— ii.	March 10 0	137	35	84	0·637
121	103	1785 i.	Jan. 27 7	109 51	264 12	70 14	1·1434
122	104	— ii.	April 8 8	297 29	64 33	87 31	0·4273
123	105	1786 i.	Jan. 30 20	156 38	334 8	13 36	0·3348
124	106	— ii.	July 7 21	159 25	194 22	50 54	0·4101
125	107	1787	May 10 19	7 44	106 51	48 15	0·3489
126	108	1788 i.	Nov. 10 7	99 8	156 56	12 27	1·0630
127	109	— ii.	Nov. 20 7	22 49	352 24	64 30	0·7573
128	110	1790 i.	Jan. 15 5	60 14	176 11	31 54	0·7581
129	111	— ii.	Jan. 28 7	111 44	267 8	56 58	1·0632
130	112	— iii.	May 21 5	273 43	33 11	63 52	0·7979
131	113	1792 i.	Jan. 13 13	36 29	190 46	39 46	1·2930
132	114	— ii.	Dec. 27 6	135 59	283 15	49 1	0·9662
133	115	1793 i.	Nov. 4 20	228 42	108 29	60 21	0·4034
134	116	— ii.	Nov. 20 5	71 54	2 0	51 31	1·4951
135	(105)	1795	Dec. 21 10	156 41	334 39	13 42	0·3344
136	117	1796	April 2 19	192 44	17 2	64 54	1·5781
137	118	1797	July 9 2	49 27	329 15	50 40	0·5266
138	119	1798 i.	April 4 11	104 59	122 9	43 52	0·4847
139	120	— ii.	Dec. 31 13	34 27	249 30	42 26	0·7795

115. Discovered by Olbers on the same day.

116. Visible to the naked eye, Nov. 9, with a tail 3° long. It came very near the Earth.

118. An elliptic orbit; period assigned, 5·613 years.

119. Visible to the naked eye, with a tail 2° long.

120. Not only are the elements uncertain, but it is doubtful whether the comet ever existed.

122. Visible to the naked eye, with a tail 8° long.

123. The first recorded apparition of *Encke's comet.*

126. Visible to the naked eye, with a tail $2\frac{1}{2}$° long.

128. Imperfectly observed on four occasions. Elements only approximate.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	—	Olbers	1780, Oct. 18	Montaigne	3 days.
1·0	+	Méchain	1781, June 28	Méchain	3 weeks.
1·0	—	Méchain	— Oct. 9	Méchain	11 weeks.
0·6784	+	Burckhardt	1783, Nov. 19	Pigott	4 weeks.
1·0	—	Méchain	— Dec. 15	La Nux	23 weeks.
1·0	+	Burckhardt	1784, April 10	D'Angos	5 days.
1·0	+	Méchain	1785, Jan. 7	Messier	5 weeks.
1·0	—	Méchain	— Mar. 11	Méchain	5 weeks.
0·84836	+	Encke	1786, Jan. 17	Méchain	3 days.
1·0	+	Méchain	— Aug. 1	Miss Herschel	12 weeks.
1·0	—	Saron	1787, April 10	Méchain	7 weeks.
1·0	—	Méchain	1788, Nov. 25	Messier	5 weeks.
1·0	+	Méchain	— Dec. 21	Miss Herschel	4 weeks.
1·0	—	Saron	1790, Jan. 7	Miss Herschel	2 weeks.
1·0	+	Méchain	— Jan. 9	Méchain	3 weeks.
1·0	—	Méchain	— April 18	Miss Herschel	10 weeks.
1·0	—	Méchain	1791, Dec. 15	Miss Herschel	6 weeks.
1·0	—	Prosperin	1793, Jan. 8	Gregory	6 weeks.
1·0	—	Saron	— Sept. 27	Messier	15 weeks.
0·97342	+	D'Arrest	— Sept. 24	Perny	10 weeks.
0·84888	+	Encke	1795, Nov. 7	Miss Herschel	3 weeks.
1·0	—	Olbers	1796, Mar. 31	Olbers	2 weeks.
1·0	—	Olbers	1797, Aug. 14	Bouvard	3 weeks.
1·0	+	Burckhardt	1798, April 12	Messier	6 weeks.
1·0	—	Burckhardt	— Dec. 6	Bouvard	1 week.

130. Visible to the naked eye, with a tail 4° long.

132. Discovered by Méchain and Piazzi, Jan. 10. There was a trace of a tail to be seen.

134. Discovered by Miss Herschel, Oct. 7. An elliptic orbit; period assigned, 422 years.

135. An apparition of *Encke's comet.* It was just visible to the naked eye.

136. Very faint.

137. Discovered by Miss Herschel and Lee on the same evening; by Rüdiger, Aug. 15, and by Kecht, Aug. 16.

139. Discovered by Olbers, Dec. 18. Elements only approximate.

No.	No.	Year.	PP.		π	☊	ι	q
				d. h.	° ′	° ′	° ′	
140	121	1799 i.	Sept.	7 5	3 39	99 32	50 56	0·8399
141	(61)	— ii.	Dec.	25 21	190 20	326 49	77 1	0·6258
142	122	1801	Aug.	8 13	182 41	42 28	20 45	0·2564
143	123	1802	Sept.	9 21	332 9	310 15	57 0	1·0941
144	124	1804	Feb.	13 15	148 53	176 49	56 44	1·0772
145	(105)	1805	Nov.	21 12	156 47	334 20	13 33	0·3404
146	(92)	1806 i.	Jan.	1 23	109 32	251 15	13 38	0·9068
147	125	— ii.	Dec.	28 22	97 2	322 19	35 2	1·0815
148	126	1807	Sept.	18 17	270 54	266 47	63 10	0·6461
149	127	1808 ii.	May	12 22	69 12	322 58	45 43	0·3898
150	128	— iii.	July	12 4	252 38	24 11	39 18	0·6079
151	129	1810	Oct.	5 1	64 56	308 35	63 5	0·9685
152	130	1811 i.	Sept.	12 6	75 0	140 24	73 2	1·0354
153	131	— ii.	Nov.	10 23	47 27	93 1	31 17	1·5821
154	132	1812	Sept.	15 7	92 18	253 1	73 57	0·7771
155	133	1813 i.	March	4 12	69 56	60 48	21 13	0·6991
156	134	— ii.	May	19 10	197 43	42 40	81 2	1·2161
157	135	1815	April	25 23	149 2	83 28	44 29	1·2128
158	136	1816	March	1 8	267 35	323 14	43 5	0·0485
159	137	1818 i.	Feb.	3 5	76 18	256 1	34 11	0·6959
160	138	— ii.	Feb.	25 23	182 45	70 26	89 43	1·1977
161	139	— iii.	Dec.	4 22	101 55	89 59	63 5	0·8550
162	(105)	1819 i.	Jan.	27 6	156 59	334 33	13 36	0·3352

140. Discovered by Olbers, Aug. 26. At first faint, but afterwards visible to the naked eye, with a tail 10° long.

141. Probably a return of the comet of 1699. Visible to the naked eye, with a tail from 1° to 3° long.

142. Discovered at Paris, July 12. Elements resemble those of the comet of 1462.

143. Discovered by Méchain, Aug. 28, and by Olbers, Sept. 2.

144. Discovered by Bouvard, March 10, and by Olbers, March 12.

145. An apparition of *Encke's comet.* Discovered by Pons, Huth, and Bouvard, Oct. 20. Visible to the naked eye, with a tail 3° long.

146. An apparition of *Biela's comet.* Discovered by Bouvard, Nov. 16, and by Huth, Nov. 22. Visible to the naked eye.

148. Discovered by Pons, Sept. 20. It was visible to the naked eye, with a tail 5° long. An elliptic orbit; period assigned, 1714 years, which may, however, be extended to 2157 years or reduced to 1403 years.

149. Discovered by Wisniewski, March 29.

150. Elements only approximate.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	−	Burckhardt	1779, Aug. 7	Méchain	3 weeks.
1·0	−	Méchain	— Dec. 26	Méchain	10 days.
1·0	−	Doberck	1801, June 30	Reissig	3 weeks.
1·0	+	Olbers	1802, Aug. 26	Pons	6 weeks.
1·0	+	Bouvard	1804, Mar. 7	Pons	3 weeks.
0·84617	+	Encke	1805, Oct. 19	Thulis	3 weeks.
0·74578	+	Gambart	— Nov. 10	Pons	4 weeks.
1·0	−	Burckhardt	1806, Nov. 10	Pons	14 weeks.
0·99548	+	Bessel	1807, Sept. 9	Parisi	28 weeks.
1·0	−	Encke	1808, Mar. 25	Pons	1 week.
1·0	−	Bessel	— June 24	Pons	10 days.
1·0	+	Thraen	1810, Aug. 22	Pons	6 weeks.
0·99509	−	Argelander	1811, Mar. 26	Flaugergues	17 months.
0·98271	+	Nicolai	— Nov. 16	Pons	13 weeks.
0·95454	+	Encke	1812, July 20	Pons	10 weeks.
1·0	−	Nicollett	1813, Feb. 4	Pons	5 weeks.
1·0	−	Encke	— Mar. 28	Pons	6 weeks.
0·93121	+	Bessel	1815, Mar. 6	Olbers	25 weeks.
1·0	+	Burckhardt	1816, Jan. 22	Pons	11 days.
1·0	+	Hind	1818, Feb. 23	Pons	4 days.
1·0	+	Encke	1817, Dec. 26	Pons	18 weeks.
1·0	−	Rosenberger	1818, Nov. 28	Pons	9 weeks.
0·84858	+	Encke	— Nov. 26	Pons	7 weeks.

152. A very celebrated comet, conspicuously visible in the evenings of the autumn of 1811. It had a tail 25° long and 6° broad. The most reliable computations assign a periodic term of 3065 years, subject to an uncertainty of not more than 43 years. The orbit of this comet is liable to much planetary perturbation.

153. An elliptic orbit; period assigned, 875 years. Visible to the naked eye.

154. An elliptic orbit; period assigned, 70·68 years. Visible to the naked eye, with a tail 2° long.

156. Discovered also by Harding, April 3. Visible to the naked eye.

157. An elliptic orbit; period assigned, 70·049 years. Bessel anticipated that planetary perturbation would bring it back to perihelion, 1887, Feb. 9. It had a short tail.

158. Elements only approximate.

159. The observations were few and indifferent.

161. Discovered by Bessel, Dec. 22. It moved very rapidly. Rosenberger has computed a hyperbolic orbit.

162. An apparition of *Encke's comet*, the periodicity of which was now discovered.

No.	No.	Year.	PP.		π	☊	ι	q
				d. h.	° ′	° ′	° ′	
163	140	1819 ii.	June	27 17	287 5	273 42	80 44	0·3410
164	141	— iii.	July	18 21	274 40	113 10	10 42	0·7736
165	142	— iv.	Nov.	20 5	67 18	77 13	9 1	0·8925
166	143	1821	March	21 12	239 29	48 40	73 3	0·0918
167	144	1822 i.	May	5 14	192 43	177 26	53 37	0·5044
168	(105)	— ii.	May	23 23	157 11	334 25	13 20	0·3459
169	145	— iii.	July	15 20	219 59	97 44	36 18	0·8473
170	146	— iv.	Oct.	23 18	271 40	92 44	52 39	1·1450
171	147	1823	Dec.	9 10	274 34	303 3	76 11	0·2265
172	148	1824 i.	July	11 12	260 16	234 19	54 34	0·5912
173	149	— ii.	Sept.	29 1	4 31	279 15	54 36	1·0501
174	(112)	1825 i.	May	30 13	273 55	20 6	56 41	0·8891
175	150	— ii.	Aug.	18 17	10 14	192 56	89 41	0·8834
176	(105)	— iii.	Sept.	16 6	157 14	334 27	13 21	0·3448
177	151	— iv.	Dec.	10 16	318 46	215 43	33 32	1·2408
178	(92)	1826 i.	March	18 9	109 45	251 28	13 33	0·9025
179	152	— ii.	April	21 23	116 54	197 38	40 2	2·0111
180	153	— iii.	April	29 0	35 48	40 29	5 17	0·1881
181	154	— iv.	Oct.	8 22	57 48	44 6	25 57	0·8528
182	155	— v.	Nov.	18 9	315 31	235 7	89 22	0·0268
183	156	1827 i.	Feb.	4 22	33 30	184 27	77 35	0·5065
184	157	— ii.	June	7 20	297 31	318 10	43 38	0·8081

163. A very brilliant comet, with a tail 7° long.

164. An elliptic orbit; period assigned, 5·618 years. Considered by Clausen as a return of the comet of 1766 (ii).

165. Discovered by Pons, Dec. 4. An elliptic orbit; period assigned, 4·810 years. Clausen thought this comet might be identical with that of 1743 (i).

166. Discovered by Nicollet on the same day, and by Blainpain, Jan. 25. Visible to the naked eye, with a tail 2½° long.

167. Discovered by Pons, May 14, and by Biela, May 17.

168. The first predicted apparition of *Encke's comet.* Seen only in New South Wales.

169. Its apparent motion was very rapid.

170. Discovered by Gambart, July 16. An elliptic orbit; period assigned, 5444 years. Visible to the naked eye, with a tail 1½° long.

171. Discovered by Pons, Dec. 29; by Kohler, Dec. 30; and by Santini, Jan. 3. This comet had, in addition to the usual tail turned from the Sun, another turned *towards it.*

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Bouvard	1819, July 1	Tralles	16 weeks.
0·75519	+	Encke	— June 12	Pons	5 weeks.
0·68674	+	Encke	— Nov. 28	Blainpain	8 weeks.
1·0		Rosenberger	1821, Jan. 21	Pons	15 weeks.
1·0	—	Nicollet	1822, May 12	Gambart	7 weeks.
0·84446	+	Encke	— June 2	Rümker	3 weeks.
1·0	—	Hind	— May 31	Pons	2 weeks.
0·99630	—	Encke	— July 13	Pons	17 weeks.
1·0	—	Encke	1823, Dec. 1	In Switzerland	13 weeks.
1·0	—	Rümker	1824, July 15	Rümker	4 weeks.
1·00173	+	Encke	— July 23	Scheithauer	22 weeks.
1·0	—	Clausen	1825, May 19	Gambart	8 weeks.
1·0	+	Clausen	— Aug. 9	Pons	3 weeks.
0·84488	+	Encke	— July 13	Valz	8 weeks.
0·99536	—	Hansen	— July 15	Pons	12 months.
0·74657	+	Santini	1826, Feb. 27	Biela	8 weeks.
1·0	+	Clausen	1825, Nov. 6	Pons	22 weeks.
1·0	—	Clüver	1826, Mar. 29	Flaugergues	9 days.
1·0	+	Argelander	— Aug. 7	Pons	15 weeks.
1·0	—	Clüver	— Oct. 22	Pons	11 weeks.
1·0	—	Heiligenstein	— Dec. 26	Pons	5 weeks.
1·0	—	Heiligenstein	1827, June 20	Pons	4 weeks.

172. Seen only in the southern hemisphere.

173. Discovered by Pons, July 24, and afterwards by Gambart and Harding.

174. It had a tail $1\frac{1}{2}°$ long. Elements resemble those of 1790 (iii).

175. Discovered by Harding, Aug. 23. Orbit remarkable for its great inclination.

176. An apparition of *Encke's comet.* Discovered by Plana, Aug. 10, and by Pons, Aug. 14.

177. Discovered by Biela, July 19. Very conspicuous early in October, with a bifid tail 15° long. An elliptic orbit; period assigned, 4386 years.

178. An apparition of *Biela's comet,* whose periodicity was now discovered. Found by Gambart, March 9.

180. Elements uncertain.

181. The path of this comet crosses the ecliptic near the Earth's orbit.

182. Discovered by Clausen, Oct. 26, and by Gambart, Oct. 28. Visible to the naked eye, with a tail $\frac{1}{4}°$ long.

184. Discovered also by Gambart. Elements resemble those of the comet of 1500.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
185	158	1827 iii.	Sept.	11	6	250	57	149	39	54	4	0·1378
186	(105)	1829	Jan.	9	17	157	17	334	29	13	20	0·3455
187	159	1830 i.	April	9	7	212	11	206	21	21	16	0·9214
188	160	— ii.	Dec.	27	15	310	59	337	53	44	45	0·1258
189	(105)	1832 i.	May	3	23	157	21	334	32	13	22	0·3434
190	161	— ii.	Sept.	25	12	227	55	72	27	43	18	1·1839
191	(92)	— iii.	Nov.	26	2	110	0	248	15	13	13	0·8790
192	162	1833	Sept.	10	4	222	51	323	0	7	21	0·4584
193	163	1834	April	2	15	276	33	226	48	5	56	0·5150
194	164	1835 i.	March	27	13	207	42	58	19	9	7	2·0413
195	(105)	— ii.	Aug.	26	8	157	23	334	34	13	21	0·3444
196	(4)	— iii.	Nov.	15	22	304	31	55	9	17	45	0·5865
197	(105)	1838	Dec.	19	0	157	27	334	36	13	21	0·3440
198	165	1840 i.	Jan.	4	10	192	11	119	57	53	5	0·6184
199	166	— ii.	March	13	2	80	12	236	50	59	12	1·2204
200	(16)	— iii.	April	2	12	324	20	186	4	79	51	0·7420
201	167	— iv.	Nov.	13	15	22	31	248	56	57	57	1·4808
202	(105)	1842 i.	April	12	0	157	29	334	39	13	20	0·3450
203	168	— ii.	Dec.	15	22	327	17	207	49	73	34	0·5044
204	169	1843 i.	Feb.	27	9	278	39	1	12	35	41	0·0055
205	170	— ii.	May	6	1	281	29	157	14	52	44	1·6163
206	171	— iii.	Oct.	17	3	49	34	209	29	11	22	1·6925

185. At one time supposed to be a return of the comet of 1780 (i). An elliptic orbit; period assigned, 2611 years.

186. An apparition of *Encke's comet*, afterwards visible to the naked eye.

187. Discovered in the southern hemisphere. Visible to the naked eye, with a tail 8° long.

188. Visible to the naked eye, with a tail 2½° long.

189. An apparition of *Encke's comet*. Discovered by Henderson, June 2. Only one observation was made in Europe.

190. Discovered by Harding, July 29.

191. The first predicted apparition of *Biela's comet*.

193. Discovered by Dunlop, March 16.

195. An apparition of *Encke's comet*. Discovered by Boguslawski. July 30.

196. The second predicted return of *Halley's comet*. It was visible to the naked eye during the whole of October, with a tail from 20° to 30° long.

197. An apparition of *Encke's comet*. Discovered by Galle, Sept. 16. Perceptible to the naked eye, Nov. 7.

202. An apparition of *Encke's comet*.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·99927	—	Clüver	1827, Aug. 2	Pons	10 weeks.
0·84462	+	Encke	1828, Oct. 13	Struve	15 weeks.
0·99938	+	Hädenkamp and Mayer	1830, March 16	D'Abbadie	22 weeks.
1·0	—	Wolfers	1831, Jan. 7	Herapath	9 weeks.
0·84541	+	Encke	1832, June 1	Mossotti	?
1·0	—	C. A. Peters	— July 19	Gambart	4 weeks.
0·75146	+	Santini	— Aug. 25	Dumouchel	18 weeks.
1·0	+	C. A. Peters	1833, Oct. 1	Dunlop	2 weeks.
1·0	+	Petersen	1834, March 8	Gambart	6 weeks.
1·0	—	W. Bessel	1835, April 20	Boguslawski	5 weeks.
0·84503	+	Encke	— July 22	Kreil	9 weeks.
0·96739	—	Westphalen	— Aug. 6	Dumouchel	41 weeks.
0·84517	+	Encke	1838, Aug. 14	Boguslawski	16 weeks.
1·00020	+	Peters, Struve	1839, Dec. 3	Galle	10 weeks.
0·99323	—	Loomis	1840, Jan. 25	Galle	9 weeks.
1·0	+	Petersen	— March 6	Galle	3 weeks.
0·96985	+	Götze	— Oct. 27	Bremiker	16 weeks.
0·84479	+	Encke	1842, Feb. 8	Galle	15 weeks.
1·0	—	Petersen	— Oct. 28	Laugier	4 weeks.
0·99989	—	Hubbard	1843, Feb. 28	Many observers.	7 weeks.
1·00017	+	Götze	— May 2	Mauvais	21 weeks.
0·55596	+	Le Verrier	— Nov. 22	Faye	20 weeks.

198. Perceptible to the naked eye, Jan. 8.

199. An elliptic orbit; period assigned, 2423 years. Plantamour, however, makes it 13,864 years.

200. Probably a return of the comet of 1097. It had a tail 5° long.

201. An elliptic orbit; period assigned, 344 years, subject to an uncertainty of about 8 years. Possibly a return of the comet of 1490.

202. An apparition of *Encke's comet.*

203. Small and faint.

204. One of the finest comets of the present century. It had a tail 60° long. The orbit is remarkable for its small perihelion distance. The period assigned is 376 years. This may be a return of the comet of 1668, but many others have also been supposed to be identical with it. (See Cooper's *Cometic Orbits*, pp. 162–9.)

206. Usually known as *Faye's comet.* It had a very small tail. Period, 7·44 years.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° ′	° ′	° ′	
207	(53?)	1844 i.	Sept. 2 11	342 30	63 49	2 54	1·1864
208	172	— ii.	Oct. 17 8	180 24	31 39	48 36	0·8553
209	173	— iii.	Dec. 13 16	296 0	118 23	45 36	0·2512
210	174	1845 i.	Jan. 8 3	91 19	336 44	46 50	0·9051
211	175	— ii.	April 21 0	192 33	347 6	56 23	1·2546
212	(44)	— iii.	June 5 16	262 2	337 48	48 41	0·4016
213	(105)	— iv.	Aug. 9 15	157 44	334 19	13 7	0·3381
214	176	1846 i.	Jan. 22 2	89 6	111 8	47 26	1·4807
215	(92)	— ii.	Feb. 10 23	109 2	245 54	12 34	0·8564
216	177	— iii.	Feb. 25 7	116 28	102 37	30 57	0·6500
217	178	— iv.	March 5 12	90 27	77 33	85 6	0·6637
218	179	— v.	May 27 21	82 32	161 18	57 35	1·3762
219	180	— vi.	June 1 5	240 7	260 28	30 24	1·5287
220	181	— vii.	June 5 12	162 0	261 51	29 18	0·6334
221	182	— viii.	Oct. 29 17	98 35	4 41	49 41	0·8306
222	183	1847 i.	March 30 6	276 2	21 42	48 39	0·0425
223	184	— ii.	June 4 18	141 34	173 56	79 34	2·1161
224	185	— iii.	Aug. 9 8	21 17	76 43	32 38	1·4847
225	186	— iv.	Aug. 9 10	246 41	338 17	83 27	1·7671
226	187	— v.	Sept. 9 13	79 12	309 48	19 8	0·4879
227	188	— vi.	Nov. 14 9	274 14	190 50	71 53	0·3291
228	189	1848 i.	Sept. 8 1	310 34	211 32	84 24	0·3199
229	(105)	— ii.	Nov. 26 2	157 47	334 22	13 8	0·3370

207. Visible to the naked eye. An elliptic orbit; period assigned, 5·469 years. It has not been observed since. Possibly identical with the comet of 1678.

208. Discovered by D'Arrest, July 9. Visible to the naked eye, Nov. 10. Period, 102,050 years, subject to an uncertainty of 3090 years.

209. First seen in the southern hemisphere. It had a tail 10° long.

211. Discovered by Faye, March 6.

212. Discovered by Richter, June 6. A fine comet. Visible to the naked eye, with a tail 2½° long. A return of the comet of 1596. Period, 250 years.

213. An apparition of *Encke's comet.* Discovered by Di Vico, July 9, and by Coffin, July 10.

214. An elliptic orbit; period assigned, 2721 years.

215. An apparition of *Biela's comet.* Discovered by Galle, Nov. 28. It was at this return that the comet separated into 2 parts.

216. An elliptic orbit; period assigned, 5·58 years.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·61765	+	Brünnow	1844, Aug. 22	Di Vico	19 weeks.
0·99960	—	Plantamour	— July 7	Mauvais	35 weeks.
1·0	+	Hind	— Dec. 19	Wilmot	12 weeks.
1·0	+	Götze	— Dec. 28	D'Arrest	13 weeks.
1·0	+	Faye	1845, Feb. 25	Di Vico	9 weeks.
0·98987	—	D'Arrest	— June 2	Colla	4 weeks.
0·84743	+	Encke	— July 4	Walker	10 days.
0·99240	+	Jelinek	1846, Jan. 24	Walker	14 weeks.
0·75700	+	Plantamour	1845, Nov. 26	Walker	21 weeks.
0·79446	+	Hind	1846, Feb. 26	Brorsen	8 weeks.
0·96224	+	Peirce	— Feb. 20	Di Vico	10 weeks.
1·0	—	Argelander	— July 29	Di Vico	11 weeks.
0·72133	—	C. H. Peters	— June 26	C. H. Peters	4 weeks.
0·98836	—	Wichmann	— April 30	Brorsen	6 weeks.
1·0	+	Hind	— Sept. 23	Di Vico	3 weeks.
0·99991	+	Hornstein	1847, Feb. 6	Hind	11 weeks.
1·0	—	Von Littrow	— May 7	Colla	30 weeks.
1·0	—	Schweizer	— Aug. 31	Schweizer	13 weeks.
1·0	—	Von Littrow	— July 4	Mauvais	41 weeks.
0·97256	+	D'Arrest	— July 20	Brorsen	8 weeks.
1·0	—	D'Arrest	— Oct. 1	Miss Mitchell	13 weeks.
1·0	—	Sonntag and Quirling	1848, Aug. 7	Petersen	3 weeks.
0·84782	+	Encke	— Aug. 27	G. P. Bond	13 weeks.

217. Discovered by G. P. Bond, Feb. 26.

218. Discovered by Hind, 2 hours later.

219. Discovered by Di Vico, July 2. An elliptic orbit; period assigned, 12·8 years, subject to an uncertainty of 1 year.

220. Discovered by Wichmann, May 1. Visible to the naked eye, May 14. An elliptic orbit; period assigned, 400 years.

222. Visible in the daytime. It had a tail $1\frac{1}{2}°$ long. The true elements are probably elliptical. Hornstein has throughly discussed the orbit of this comet.

225. A parabolic orbit best satisfies the observations.

226. Period assigned, 75 years.

227. Discovered by Di Vico, Oct. 3; by Dawes, Oct. 7; and by Madame Rümker, Oct. 11.

229. An apparition of *Encke's comet*. Discovered by Hind, Sept. 13. Perceptible to the naked eye, Oct. 6. On Nov. 3 it had a tail more than 1° long.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
230	190	1849 i.	Jan.	19	8	63	11	215	10	85	4	0·9599
231	191	— ii.	May	26	11	235	43	202	33	67	9	1·1593
232	192	— iii.	June	8	4	267	3	30	31	66	59	0·8946
233	193	1850 i.	July	23	12	273	24	92	53	68	12	1·0815
234	194	— ii.	Oct.	19	8	89	20	206	0	40	6	0·5647
235	(171)	1851 i.	April	3	11	49	42	209	30	11	21	1·6999
236	195	— ii.	July	9	0	324	10	149	19	14	14	1·1847
237	196	— iii.	Aug.	26	5	310	58	223	40	38	9	0·9843
238	197	— iv.	Sept.	30	19	338	45	44	28	74	0	0·1410
239	(105)	1852 i.	March	14	18	157	51	334	23	13	7	0·3374
240	198	— ii.	April	19	13	280	0	317	8	48	52	0·9050
241	(92)	— iii.	Sept.	23	1	109	8	245	52	12	33	0·8606
242	199	— iv.	Oct.	12	15	43	12	346	13	40	58	1·2510
243	200	1853 i.	Feb.	24	6	153	21	69	49	20	19	1·0938
244	201	— ii.	May	9	16	201	53	40	57	57	44	0·9044
245	202	— iii.	Sept.	1	17	310	56	140	31	61	31	0·3068
246	203	— iv.	Oct.	16	14	302	7	220	4	61	1	0·1725
247	204	1854 i.	Jan.	4	6	55	57	227	3	66	7	1·2002
248	205	— ii.	March	24	0	213	47	315	26	82	22	0·2770
249	(13)	— iv.	June	22	2	272	58	347	48	71	8	0·6475
250	206	— v.	Oct.	27	9	94	20	324	34	40	59	0·8001

230. A parabolic orbit satisfies the observation, but a period of 382,801 years has been assigned!!!

231. It had a small tail.

232. Discovered a few hours later by Bond, and by Graham April 14. Period, 8375 years.

233. Visible to the naked eye, with a tail. Carrington has assigned a period of about 29,000 years.

234. Discovered by Brorsen, Sept. 5; by Mauvais and Robertson, Sept. 9; and by Clausen, Sept. 14.

235. The first predicted apparition of *Faye's comet.*

236. Period, 6·441 years.

237. Discovered by Schweizer, Aug. 21. Period assigned, 5544 years.

238. It had a tail more than 1° long, and also a shorter one turned towards the Sun.

239. An apparition of *Encke's comet.*

240. Discovered by Petersen, May 17, and by G. P. Bond, May 19. It was very small and faint.

241. An apparition of *Biela's comet.* Theoretical elements.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Pogson	1848, Oct. 26	Petersen	20 weeks.
1·0	+	Goujon	1849, April 15	Goujon	24 weeks.
0·99783	+	D'Arrest	— April 11	Schweizer	20 weeks.
1·0	+	Villarceau	1850, May 1	Petersen	17 weeks.
1·0	+	Reslhüber	— Aug. 29	G. P. Bond	9 weeks.
0·55501	+	Le Verrier	— Nov. 28	Challis	14 weeks.
0·70001	+	D'Arrest	1851, June 27	D'Arrest	17 weeks.
0·99685	+	Brorsen	— Aug. 1	Brorsen	8 weeks.
1·0	+	J. Breen	— Oct. 22	Brorsen	4 weeks.
0·84767	+	Encke	1852, Jan. 9	Hind	8 weeks.
1·0	—	Sonntag	— May 15	Chacornac	3 weeks.
0·75625	+	Santini	— Aug. 25	Secchi	5 weeks.
0·92475	+	Marth	— June 27	Westphal	24 weeks.
1·0	—	D'Arrest	1853, March 6	Secchi	3 weeks.
1·0	—	Bruhns	— April 4	Schweizer	10 weeks.
1·00026	+	Krahl	— June 10	Klinkerfues	7 months.
1·0	—	Bruhns	— Sept. 11	Bruhns	11 weeks.
1·0	—	Marth	— Nov. 25	Van Arsdale	12 weeks.
1·0	—	Hornstein	1854, March 23	Many observers	6 weeks.
1·0	—	Bruhns	— June 4	Klinkerfues	10 weeks.
1·0	+	Bruhns	— Sept. 11	Klinkerfues	11 weeks.

242. Discovered also by C. H. Peters. Visible to the naked eye early in October. Period, 70 years.

243. Discovered by Schweitzer and C. W. Tuttle, March 8, and by Hartwig, March 10. Elements resemble those of the comet of 1664.

244. Visible to the naked eye in the beginning of May, with a tail 3° long.

245. Visible in the daytime, Aug. 31 to Sept. 4. In the south of Europe, a tail 15° long was seen.

246. Perceptible to the naked eye about the middle of the month. Elements resemble those of the comet of 1582.

247. Discovered by Klinkerfues, Dec. 2.

248. First seen in the south of France, when very conspicuous, with a tail 4° long. Elements resemble those of the comet of 1799 (ii).

249. Discovered also by Van Arsdale. At the time of the PP it was visible to the naked eye. The elements strongly resemble those of the comets of 961 and 1558.

250. Discovered also by several other observers. Probably a return of the comet of 1845 (i).

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
251	207	1854 vi.	Dec.	15	17	165 9	238 7	14 9	1·3575
252	208	1855 i.	Feb.	5	17	226 33	189 40	51 12	1·2195
253	(22)	— iii.	May	30	5	237 36	260 15	23 7	0·5678
254	(105)	— iv.	July	1	5	157 53	334 26	13 8	0·3371
255	209	— v.	Nov.	25	15	85 21	52 2	10 16	1·2248
256	210	1857 i.	March	21	8	74 49	313 12	87 57	0·7721
257	(177)	— ii.	March	29	5	115 48	101 53	29 45	0·6202
258	211	— iii.	July	17	23	249 37	23 40	58 59	0·3675
259	212	— iv.	Aug.	24	0	21 46	200 49	32 46	0·7427
260	213	— v.	Sept.	30	19	250 21	14 46	56 18	0·5651
261	214	— vi.	Nov.	19	1	44 15	139 18	37 50	1·1009
262	(195)	— vii.	Dec.	33	0	323 3	148 27	13 56	1·1696
263	(111)	1858 i.	Feb.	23	8	115 29	268 54	54 32	1·0274
264	(141)	— ii.	May	2	1	275 38	113 32	10 48	0·7689
265	215	— iii.	May	2	23	200 46	175 4	19 30	1·1493
266	216	— iv.	June	5	4	226 6	324 21	80 28	0·5462
267	(171)	— v.	Sept.	12	14	49 49	209 45	11 21	1·6999
268	217	— vi.	Sept.	29	23	36 13	165 19	63 1	0·5784
269	218	— vii.	Oct.	12	19	4 13	159 45	21 16	1·4270
270	(105)	— viii.	Oct.	18	8	157 57	334 28	13 4	0·3407
271	219	1859 ii.	May	29	5	75 9	357 7	84 9	0·2020
272	220	1860 i.	Feb.	16	17	173 45	324 3	79 35	1·1973

251. Discovered by Winnecke and Dien, Jan. 15, 1855.

253. Discovered also by Dien and Klinkerfues. Probably a return of the comet of 1362 (i). Period assigned, 493 years.

254. An apparition of *Encke's comet.*

255. Discovered also by Van Arsdale.

256. Discovered also by Van Arsdale. Orbit decidedly parabolic.

257. An apparition of *Brorsen's comet*, 1846 (iii).

259. Discovered by Dien, July 28, and by Habicht, July 30. An elliptic orbit; period assigned, 234 years.

260. Faintly perceptible to the naked eye, Sept. 20. It had a short tail. Elements resemble those of the comets of 1790 (iii) and 1825 (i). A period of 1618 years has been assigned by Villarceau.

261. Discovered a few hours later by Van Arsdale.

262. An apparition of *D'Arrest's comet.* Period, 2366 days. Lind and Villarceau concur in dating the PP for Nov. 28.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·98637	+	Elkin	1854, Dec. 24	Colla	16 weeks.
1·0	–	Winnecke	1855, April 11	Schweizer	5 weeks.
0·99090	–	Donati	— June 3	Donati	2 weeks.
0·84778	+	Encke	— July 13	Maclear	5 weeks.
1·0	–	G. Rümker	— Nov. 12	Bruhns	7 weeks.
1.0	+	Pape	1857, Feb. 22	D'Arrest	9 weeks.
0·80160	+	Bruhns	— Mar. 18	Bruhns	11 weeks.
1·0	–	Pape	— June 22	Klinkerfues	3 weeks.
0·98037	+	Möller	— July 25	C. H. Peters	5 weeks.
1·0	–	Bruhns	— Aug. 20	Klinkerfues	7 weeks.
1·0	–	Pape	— Nov. 10	Donati	5 weeks.
0·65985	+	Schulze	— Dec. 5	Maclear	6 weeks.
0·82961	+	Bruhns	1858, Jan. 4	H. P. Tuttle	9 weeks.
0·75467	+	Winnecke	— Mar. 8	Winnecke	12 weeks.
0·67368	+	Schulhof	— May 2	Tuttle	4 weeks.
1·0	–	Bruhns	— May 21	Bruhns	3 weeks.
0·55501	+	Bruhns	— Sept. 8	Bruhns	8 weeks.
0·99620	–	Von Asten	— June 2	Donati	7½ months.
1·0	–	Weiss	— Sept. 5	H. P. Tuttle	8 weeks.
0·84639	+	Powalky	— Aug. 7	Förster	10 weeks.
1·0	–	Hall	1859, April 2	Tempel	12 weeks.
1·0	+	Liais	1860, Feb. 26	Liais	2 weeks.

263. Discovered by Bruhns, Jan. 11. Probably a return of the comet of 1790 (ii). Period assigned, 13·6 years.

264. An apparition of the comet of 1819 (iii), now called *Winnecke's Comet.*

266. Elements resemble those of the comet of 1799 (ii).

267. An apparition of *Faye's comet.*

268. One of the finest comets of the present century. It became visible to the naked eye early in September, and was very conspicuously seen in Europe for about 6 weeks, when, owing to its rapid passage to the southern hemisphere, it became lost to view. It was seen at the Cape of Good Hope till March 4, 1859. During the first week in October it had a tail nearly 40° long. An elliptic orbit; period assigned, 1879 years.

270. An apparition of *Encke's comet.* It was very faint.

272. It does not appear that this comet was seen in Europe. Liais, who observed it in Brazil, states that it had a double nebulosity, and conjectures it to be identical with 1845 (ii), 1785 (i), and 1351.

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
273	221	1860 ii.	March	5	17	50 16	8 56	48 13	1·3083
274	222	— iii.	June	16	2	161 32	84 40	79 18	0·2929
275	223	— iv.	Sept.	22	7	356 48	44 51	32 12	0·6827
276	224	1861 i.	June	3	8	243 22	29 55	79 45	0·9207
277	225	— ii.	June	11	12	249 4	278 58	85 26	0·8223
278	226	— iii.	Dec.	7	3	173 30	145 6	41 57	0·8391
279	(105)	1862 i.	Feb.	6	4	158 0	334 30	13 5	0·3399
280	227	— ii.	June	22	1	299 20	326 32	7 54	0·9813
281	228	— iii.	Aug.	22	22	344 41	137 26	66 25	0·9626
282	229	— iv.	Dec.	28	3	125 9	355 44	42 22	0·8025
283	230	1863 i.	Feb.	3	12	191 22	116 55	85 22	0·7947
284	231	— ii.	April	4	22	247 15	251 16	67 22	1·0682
285	232	— iii.	April	20	21	305 47	250 10	85 29	0·6288
286	233	— iv.	Nov.	9	12	94 43	97 29	78 5	0·7066
287	(129)	— v.	Dec.	26	14	59 13	304 57	63 35	0·7661
288	234	— vi.	Dec.	29	4	183 8	105 1	83 18	1·3131
289	235	1864 i.	July	27	21	190 10	175 11	44 56	0·6140
290	236	— ii.	Aug.	15	14	304 13	95 12	1 52	0·9092
291	237	— iii.	Oct.	11	8	159 30	31 43	70 13	0·9338
292	238	— iv.	Dec.	22	11	321 42	203 13	48 52	0·7709
293	239	— v.	Dec.	27	18	162 22	340 53	17 7	1·1145
294	240	1865 i.	Jan.	14	7	141 15	253 3	87 32	0·0260

274. Suddenly became visible towards the end of June. On the 22nd it had a tail 15° long. Liais has assigned a period of 1089 years.

275. Very faint, and only 4 observations obtained. Elements therefore very uncertain.

276. Visible to the naked eye; it had a faint diffused tail 3° long: an elliptic orbit; period assigned 415·4 years.

277. One of the most magnificent comets on record: on July 2 its tail was more than 100° long. An elliptic orbit; period assigned, 419 years.

279. An apparition of *Encke's comet.*

280. Discovered by Schmidt and Tempel on July 2; on July 4 it had a tail ½° long, and was then visible to the naked eye: between July 3rd and 4th it traversed 24° of a great circle.

281. Discovered by H. P. Tuttle and Simmons, July 18; by Pacinotti, July 22; and by Rosa, July 25. Conspicuously visible to the naked eye for 2 or 3 weeks in

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Seeling	1860, April 17	C. Rümker	7 weeks.
1·0	+	Moësta	— June 19	Several observers	8 weeks.
1·0	+	Kowalczyk	— Oct. 23	Tempel	3 days.
0·98345	+	Oppolzer	1861, April 4	Thatcher	8 weeks.
0·98532	+	Seeling	— May 13	Tebbutt	12 months.
1·0	—	Pape	— Dec. 28	H. P. Tuttle	8 weeks.
0·84670	+	Powalky	— Sept. 28	Förster	22 weeks.
1·0	—	Seeling	1862, July 1	Valz	4 weeks.
0·96127	—	Oppolzer	— July 15	Swift	13 weeks.
1·0	—	Engelmann	— Nov. 30	Bruhns	3 weeks.
1·0	+	Engelmann	— Nov. 27	Respighi	15 weeks.
1·0	—	Raschkoff	1863, April 11	Klinkerfues	6 months.
1·0	+	Frischauf	— April 12	Respighi	5 weeks.
1·0	+	Oppolzer	— Nov. 4	Tempel	16 weeks.
0·94590	+	Weiss	— Dec. 28	Respighi	8 weeks.
1·0	+	Engelmann	— Oct. 9	Bäcker	7 months.
1·0	—	Celoria	1864, Sept. 9	Donati	4 weeks.
1·0	—	Kowalczyk	— July 4	Tempel	11 weeks.
1·0	—	Engelmann	— July 23	Donati	6 months.
1·0	+	Tietjen	— Dec. 15	Bäcker	7 weeks.
1·0	—	Engelmann	— Dec. 30	Bruhns	4 weeks.
1·0	—	Tebbutt	1865, Jan. 18	Moesta	10 weeks.

August—September; with a tail, on Aug. 27, as much as 25° long, according to Schmidt. An elliptic orbit; period assigned, 123 years.

283. Discovered by Bruhns, Nov. 30.

284. Visible to the naked eye in May: it had a faint tail 3° long.

285. Visible to the naked eye as a 5th mag. star.

286. Discovered independently by J. F. Schmidt, Nov. 12. Visible to the naked eye as a star of the 4th mag., with a tail 2° or more long.

287. Discovered also by Bäcker, Jan. 1, 1864. Visible to the naked eye, with a tail ½° long, at the end of January. Believed to be a return of the comet of 1810, and possibly identical with that of 1490.

288. Discovered by Tempel, Oct. 14. Two computers make the orbit a hyperbola.

290. The same computer subsequently obtained an elliptic orbit with a period of 4754 years.

294. Seen only in the southern hemisphere. On Jan. 18 it had a tail 25° long.

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
295	(105)	1865 ii.	May	27	22	158	4	324	33	13	4	0·3410
296	241	1866 i.	Jan.	11	3	60	28	231	26	17	18	0·9765
296*a*	(171)	— ii.	Feb.	13	23	49	56	209	42	11	22	1·6822
297	242	1867 i.	Jan.	19	20	75	52	78	35	18	12	1·5725
298	243	— ii.	May	23	22	236	9	101	10	6	24	1·5635
299	244	— iii.	Nov.	6	23	276	21	64	58	83	26	0·3304
300	(177)	1868 i.	April	20	23	116	2	101	14	29	22	0·5968
301	245	— ii.	June	25	23	287	7	53	40	48	11	0·5823
302	(105)	— iii.	Sept.	14	16	158	10	334	31	13	6	0·3339
303	(141)	1869 i.	June	10	23	275	55	113	33	10	48	0.7815
304	246	— ii.	Oct.	9	18	123	24	311	29	68	23	1·2306
305	247	— iii.	Nov.	18	17	42	53	296	47	5	23	1·0630
306	248	1870 i.	July	14	1	303	32	141	44	58	12	1·0087
307	249	— ii.	Sept.	2	12	17	49	12	56	80	34	1·8171
308	(195)	— iii.	Sept.	22	16	318	41	146	25	15	39	1·2803
309	250	— iv.	Dec.	19	21	4	8	94	44	32	43	0·3892
310	251	1871 i.	June	10	14	141	49	279	18	87	36	0·6543
311	252	— ii.	July	27	0	115	43	211	56	78	0	1·0835
312	(111)	— iii.	Nov.	30	11	116	5	269	17	54	17	1·0301
313	253	— iv.	Dec.	20	8	264	30	147	2	81	36	0·6944
314	(105)	— v.	Dec.	28	18	158	12	334	34	13	8	0·3329
315	(243)	1873 i.	May	9	15	237	58	78	43	9	46	1·7720
316	254	— ii.	June	25	8	306	4	120	54	12	44	1·3436
317	(171)	— iii.	July	18	11	50	5	209	41	11	22	1·6827

295. An apparition of *Encke's comet.* Perhaps seen as early as Jan. 25 by D'Arrest.

296. An elliptic orbit; period assigned, 33 years. Probably a meteor comet.

296 *a.* An apparition of *Faye's comet.*

297. An elliptic orbit; period assigned, 33·62 years.

298. Usually known as *Tempel's 1st Periodical comet.*

299. Discovered 4 hours later by Winnecke.

300. An apparition of *Brorsen's comet.* Tempel believes he sighted the comet as early as March 22.

302. An apparition of *Encke's comet.*

303. An apparition of *Winnecke's comet,* (1819, iii).

305. A comet now known as *Tempel's IIIrd Periodical comet,* or *Swift's comet.*

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·84630	+	Von Asten	1865, Feb. 13	Bruhns	5 months.
0·90541	–	Oppolzer	— Dec. 19	Tempel	7 weeks.
0·55754	+	Möller	— Aug. 22	Thiele	20 weeks.
0·84905	+	Searle	1867, Jan. 28	Tempel	10 weeks.
0·50967	+	Sandberg	— April 3	Tempel	19 weeks.
1·0	–	Oppolzer	— Sept. 27	Bäcker	5 weeks.
0·80809	+	Bruhns	1868, April 11	Tempel	9 weeks.
1·0	–	W. E. Plummer	— June 13	Winnecke	5 weeks.
0·84916	+	Von Asten	— July 14	Winnecke	6 weeks.
0·75194	+	Oppolzer	1869, April 9	Winnecke	6 months.
1·0	–	Oppenheim	— Oct. 11	Tempel	4 weeks.
0.65821	+	Zelbr	— Nov. 27	Tempel	5 weeks.
1·0	–	Dreyer	1870, May 29	Winnecke	6 weeks.
1·0	–	Hind	— Aug. 28	Coggia	17 weeks.
0·63490	+	Leveau	— Aug. 31	Winnecke	16 weeks.
1·0	–	Schulhof	— Nov. 23	Winnecke	1 week.
0·99781	+	Holetschek.	1871, April 7	Winnecke	6 weeks.
1·0	–	Schulhof	— June 14	Tempel	13 weeks.
0·82105	+	Tischler	— Oct. 12	Borrelly	15 weeks.
1·0	–	Schulhof	— Nov. 3	Tempel	15 weeks.
0·84936	+	Glasenapp	— Sept. 19	Winnecke	11 weeks.
0·46308	+	Gautier	1873, April 3	Stephan	16 weeks.
0·54978	+	Schulhof	— July 3	Tempel	15 weeks.
0·55738	+	Möller	— Sept. 3	Stephan	16 weeks.

306. It had a very short tail.

308. An apparition of *D'Arrest's comet.*

310. Discovered by Borrelly on Apr. 13, and L. Swift on Apr. 15. It had a small tail. An elliptic orbit; period assigned, 5188 years.

311. Thought to be a return of the comet of 1827 (i).

312. An apparition of *Tuttle's comet*, (1858, i).

314. An apparition of *Encke's comet.* Guessed at, rather than certainly viewed on Sept. 19. First fairly seen by Dunér on Oct. 4, and by Hind on Oct. 8.

315. An apparition of *Tempel's Ist Periodical comet.*

316 An elliptic orbit; period assigned, 5·158 years. Now known as *Tempel's IInd Periodical comet.*

317. An apparition of *Faye's comet.*

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
318	255	1873 iv.	Sept.	10	18	36 57	230 38	84 3	0·7948
319	256	— v.	Oct.	1	18	302 58	176 43	58 30	c·3848
320	(177)	— vi.	Oct.	10	12	116 5	101 15	29 23	0·5935
321	(137?)	— vii.	Dec.	3	3	85 30	248 37	26 29	0·7754
322	257	1874 i.	March	9	22	299 48	30 18	58 53	0·0445
323	258	— ii.	March	14	0	302 15	274 7	31 32	0·8861
324	259	— iii.	July	8	20	271 7	118 44	66 21	0·6757
325	260	— iv.	July	17	17	5 27	215 51	34 8	1·6883
326	261	— v.	Aug.	26	21	344 8	251 29	41 50	0·9826
327	262	— vi.	Oct.	18	22	265 41	281 58	80 47	0·5083
328	(141)	1875 i.	March	12	2	276 38	111 29	11 17	0·8289
329	(105)	— ii.	April	13	0	158 17	334 37	13 7	0·3329
330	263	1877 i.	Jan.	19	4	200 4	187 20	27 0	0·8074
331	264	— ii.	April	17	15	253 29	316 37	58 51	0·9498
332	265	— iii.	April	26	19	102 52	346 4	77 9	1·0092
333	(195)	— iv.	May	10	8	319 9	146 9	15 43	1·3181
334	266	— v.	June	27	22	83 20	184 17	64 54	1·0231
335	267	— vi.	Sept.	11	10	107 37	250 58	77 42	1·5766
336	268	1878 i.	July	20	16	279 50	102 15	78 10	1·3920
337	(105)	— ii.	July	26	3	158 20	334 39	13 7	0·3335
338	(254)	— iii.	Sept.	7	6	306 7	120 59	12 45	1·3393
339	(177)	1879 i.	March	30	8	116 44	102 16	28 59	0·5855
340	269	— ii.	April	28	1	42 44	44 57	72 45	0·8720
341	(243)	— iii.	May	6	23	238 11	78 45	9 46	1·7694
342	270	— iv.	Aug.	24	6	308 12	32 22	72 15	0·9913

320. An apparition of *Brorsen's comet.*

321. Discovered by Winnecke on Nov. 11. Probably identical with the comet of 1818 (i); but doubtful whether period is 55·8, 18·6, or 6·2 years; Prof. Weiss thinks the last-named the most probable.

324. An elliptic orbit; period assigned, 5711 years.

326. An elliptic orbit; period assigned, 306 years.

328. An apparition of *Winnecke's comet,* (1819, iii).

329. An apparition of *Encke's comet.* Discovered by Stephan, Jan. 27.

330. Discovered by Pechüle at Copenhagen, Feb. 9.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	–	W. E. Plummer	1873, Aug. 20	Borrelly	4 weeks.
1·0	–	W. E. Plummer	— Aug. 23	Henry	16 weeks.
0·80890	+	W. E. Plummer	— Aug. 31	Stephen	8 weeks.
0·77032	+	Weiss	— Nov. 10	Coggia	1 week.
1·0	+	Wittstein	1874, Feb. 20	Winnecke	1 week.
1·0	–	Schur	— April 11	Winnecke	9 weeks.
0·99788	+	Seyboth	— April 17	Coggia	6 months.
0·96283	+	Holetschek	— Aug. 19	Coggia	12 weeks.
0·99865	+	Gruber	— July 25	Borrelly	12 weeks.
1·0	–	Holetschek	— Dec. 7	Borrelly	4 weeks.
0·74101	+	Oppolzer	1875, Feb. 1	Borrelly	2 weeks.
0·84942	+	Von Asten	— Jan. 26	Holden	17 weeks.
1·0	–	Hartwig	1877, Feb. 8	Borrelly	12 weeks.
0·99770	–	Plath	— April 5	Winnecke	14 weeks.
1·0	+	Nichol	— April 11	Swift	7 weeks.
0·62780	+	Hind	— July 8	Coggia	8 weeks.
1·0	–	Schur	— Oct. 2	Tempel	2 weeks.
1·0	–	W. E. Plummer	— Sept. 13	Coggia	13 weeks.
1·0	+	Büttner	1878, July 7	Swift	2 weeks.
0·84917	+	Von Asten	— Aug. 3	Tebbutt	5 weeks.
0·55290	+	Schulhof	— July 19	Tempel	5 months.
0·81054	+	Wittstein	1879, Jan. 14	Tempel	17 weeks.
1·0	–	Abetti	— June 15	Swift	9 weeks.
0·46303	+	Gautier	— April 24	Tempel	10 weeks.
1·0	–	Hartwig	— Aug. 24	Hartwig	4 weeks.

331. Visible to the naked eye for a few days. It had two small tails, one of them turned towards the Sun. An elliptic orbit; period assigned, 8393 years.

332. Discovered by Borrelly on April 14, and by Block on April 16. An elliptic orbit, with a period of 28,000 (!) years has been assigned by Holetschek.

333. An apparition of *D'Arrest's comet.*

336. Elements uncertain; comet observed only on 4 days.

337. An apparition of *Encke's comet.*

338. An apparition of *Tempel's IInd Periodical comet.*

339. An apparition of *Brorsen's comet.*

341. An apparition of *Tempel's Ist Periodical comet.*

No.	No.	Year.	PP.			π		☊		ι		q
				d.	h.	°	′	°	′	°	′	
343	271	1879 v.	Oct.	4	16	202	27	87	7	77	6	0·9906
344	272	1880 i.	Jan.	27	10	278	23	356	17	36	52	0·0059
345	273	— ii.	July	1	0	112	28	257	9	56	54	1·8186
346	274	— iii.	Sept.	6	21	82	23	45	12	38	6	0·3542
347	(247)	— v.	Nov.	7	14	43	0	296	41	5	31	1·0692
348	275	— vi.	Nov.	8	19	184	2	257	35	50	48	0·3866
349	276	— vii.	Nov.	9	10	261	5	249	22	60	42	0·6599
350	(171)	1881 i.	Jan.	22	16	50	50	209	36	11	20	1·7383
351	277	— ii.	May	20	10	300	11	126	24	77	58	0·5911
352	278	— iii.	June	16	10	265	13	270	57	63	25	0·7344
353	279	— iv.	Aug.	22	7	334	55	97	2	39	46	0·6335
354	280	— v.	Sept.	13	10	18	36	65	52	6	50	0·7259
355	281	— vi.	Sept.	14	8	267	51	274	9	67	11	0·4492
356	(105)	— vii.	Nov.	15	1	158	30	334	34	12	53	0·3430
357	282	— viii.	Nov.	19	17	63	27	181	19	35	10	1·9261
358	283	1882 i.	June	10	13	53	55	204	55	73	48	0·0607
359	284	— iii.	Sept.	17	3	276	16	346	18	37	56	0·0082
360	285	— iv.	Sept.	24	2	232	21	354	50	29	41	0·0184
361	286	— v.	Nov.	13	0	354	48	249	7	83	51	0·9554
362	287	1883 i.	Feb.	18	22	29	0	278	7	78	4	0·7599

344. Seen only in the Southern Hemisphere. It was visible to the naked eye with a not very bright tail 40° long. The elements closely resemble those of the great comet of 1843.

346. Visible to the naked eye as a 5th mag. star with a tail 2° long. Perhaps identical with the comets of 1382, 1444, 1506, and 1569, or some of them, in which case Winnecke suggested a period of 62½ years, but the period of the orbit here given is 1280 years.

347. An apparition of the comet of 1869 (iii) now known as *Tempel's IIIrd Periodical comet*, or *Swift's comet*. Period, 6·00 years.

348. Observations, and therefore orbit, very uncertain. The whole thing probably a fraud by one Cooper.

349. Visible to the naked eye on Dec. 18 with a tail ½° long. It had indeed 2 tails, one of which was seen by C. A. Young to be directed *towards* the sun.

350. An apparition of *Faye's comet.*

352. Visible to the naked eye in June with a tail 10° long. An elliptic orbit; period assigned, 2954 years.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Zelbr	1879, Aug. 21	Palisa	9 weeks.
0·99947	–	W. Meyer	1880, Feb. 1	Many observers	3 weeks.
1·0	–	Schäberle	— April 6	Schäberle	5 months.
0·99701	–	Schulhof and [Bossert	— Sept. 29	Hartwig	9 weeks.
0·67594	+	Upton	— Oct. 10	Swift	14 weeks.
1·0	–	Oppenheim	— Dec. 21	Cooper	4 days.
1·0	+	Oppenheim	— Dec. 16	Pechüle	15 weeks.
0·54902	+	Möller	— Aug. 2	Common	8 months.
1·0	+	Gruss	1881, April 30	Swift	2 weeks.
0.99643	+	Dunér	— May 22	Tebbutt	9 months.
1·0	–	Stechert	— July 13	Schäberle	14 weeks.
0·83041	+	W. E. Plummer	— Oct. 4	Denning	6 weeks.
1·0	–	Millosevich	— Sept. 19	Barnard	6 weeks.
0·84550	+	Backlund	— Aug. 20	Hartwig	12 weeks.
1·0	–	Oppenheim	— Nov. 16	Swift	8 weeks.
1·0	+	Kreutz	1882, Mar. 17	Wells	5 months.
0·99993	–	Tatlock	— Sept. 3	Many observers	9 months.
1·0	–	Hind	— Oct. 9	Schmidt	3 days.
1·0	–	Wolyncewicz	— Sept. 13	Barnard	12 weeks.
1·0	+	Chandler and Wendell	1883, Feb. 23	Brooks	7 weeks.

353. Visible to the naked eye for 2 or 3 weeks in August with a tail which on Aug. 21 was 10° long.

354. An elliptic orbit; period assigned, 8·86 years. Thought by Winnecke to be a return of the comet of 1855 (ii).

356. An apparition of *Encke's comet.* Seen with the naked eye by Denning on Oct. 29.

357. Elements resemble those of comet i. 1792.

358. Visible with a telescope on June 10 within 3° of the Sun. A period of about 400,000 years has been assigned by F. J. Parson (*A. N.*, vol. cvii., 2550, Oct. 31, 1883).

359, 360. For important details connected with these comets see Bk. IV. ch. iii. (*ante*). No. 359 is possibly a return of the comets of 370 B.C., and 1131 or 1132 A.D., but the period of the orbit here given is 1376 years. It is noteworthy that the comet of 370 B.C. is said to have separated into 2 parts as No. 359 did. This comet was last seen with the naked eye by Thome at Cordoba on March 7, 1883. Ravene found the period to be 718 years.

362. Discovered a few hours later by Swift. It had a faint narrow tail about $\frac{1}{4}$° long.

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
363	288	1883 ii.	Dec.	25	7	125 46	264 25	65 1	0·3097
364	(132)	1884 i.	Jan.	25	20	93 20	254 6	74 3	0·7751
365	289	— ii.	Aug.	16	11	306 10	5 10	5 27	1·2793
366	290	— iii.	Nov.	17	16	18 56	206 21	25 16	1·5736
367	(105)	1885 i.	Mar.	5	21	158 33	3 34	12 54	0·3330
368	291	— ii.	Aug.	5	16	270 47	92 17	80 37	2·5068
369	292	— iii.	Aug.	10	6	247 41	204 40	59 11	0·7508
370	(111)	— iv.	Sept.	11	5	116 28	269 42	54 19	1·0260
371	293	— v.	Nov.	25	12	297 44	262 11	42 26	1·0790
372	294	1886 i.	April	5	23	162 58	36 22	82 37	0·6423
373	295	— ii.	May	3	6	188 58	68 19	84 23	0·4790
374	296	— iii.	May	4	11	326 19	287 45	79 48	0·8419
375	297	— iv.	June	6	13	229 45	53 3	12 56	1·3370
376	298	— v.	June	7	9	33 55	192 42	87 44	0·2703
377	(141)	— vi.	Sept.	16	11	276 4	101 56	14 27	0·8832
378	299	— vii.	Nov.	22	9	7 34	52 29	3 1	1·17
379	300	— viii.	Nov.	28	9	290 4	258 11	85 35	1·4800
380	301	— ix.	Dec.	16	12	223 43	137 21	78 20	0·6628
381	302	1887 i.	Jan.	11	6	274 6	337 42	43 0	0·0054
382	303	— ii.	March	16	23	120 40	279 49	75 42	1·6333
383	304	— iii.	March	28	9	171 55	135 27	40 11	1·0068
384	305	— iv.	June	16	16	260 19	245 12	17 35	1·3949
385	(135)	— v.	Oct.	8	10	149 45	84 29	44 33	1·1996
386	306	1888 i.	March	17	0	245 17	245 22	42 15	0·6987
387	(105)	— ii.	June	28	0	158 36	334 39	12 53	0·3330

364. A return of *Pons's comet of* 1812.
365. An elliptic orbit; period assigned, 5·36 years.
366. An elliptic orbit; period assigned, 6·764 years.
367. A return of *Encke's comet.*
368. Perihelion distance greater than that of any other comet save 1729.
370. A return of *Tuttle's comet* (1858, i).
372. At the end of April it reached mag. $2\frac{1}{2}$, and had a tail 4° long.
373. It had a tail 3° long. Elements resemble those of the comet of 1785 (ii).
375. An elliptic orbit; period assigned, 6·30 years.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	—	Oppenheim	1884, Jan. 7	Ross	5 weeks.
0·95499	+	Schulhof and Bossert	1883, Sept. 2	Brooks	9 months.
0·58247	+	Berberich	1884, July 16	Barnard	17 weeks.
0·55988	+	Zelbr	— Sept. 17	Wolf	7 months.
0·84575	...	Backlund	— Dec. 13	Tempel	7 weeks.
1·0	+	Berberich	1885, July 7	Barnard	8 weeks.
0·98801	+	Campbell	— Aug. 31	Brooks	5 weeks.
0·82154	+	Rahts	— Aug. 8	Perrotin	5 weeks.
1·0	+	Müller	— Dec. 26	Brooks	9 weeks.
1·0	+	Svedstrup	— Dec. 1	Fabry	8 months.
1·0	+	Hepperger	— Dec. 3	Barnard	8 months.
1·0	—	Celoria	1886, May 1	Brooks (2)	5 weeks.
0·60810	+	Hind	— May 22	Brooks (3)	6 weeks.
1·0	+	Krüger	— April 27	Brooks (1)	13 weeks.
0·72677	+	Palisa	— Aug. 9	Finlay	14 weeks.
0·71819	+	Krüger	— Sept. 26	Finlay	6 months.
1·0	+	Egbert	1887, Jan. 23	Barnard	16 weeks.
1·0	—	Svedstrup	1886, Oct. 4	Barnard	14 weeks.
1·0	—	Chandler	1887, Jan. 18	Thome	1 week.
1·0	—	Boss	— Jan. 22	Brooks	13 weeks.
1·0	—	Barnard	— Feb. 15	Barnard.	2 weeks.
1·0	+	Chandler	— May 12	Barnard.	3 months.
0·93108	+	Ginzel	— Aug. 24	Brooks.	2 months.
0·99493	+	Boss	1888, Feb. 18	Sawerthal	6 months.
0·84542	+	Backlund	— July 8	Tebbutt.	4 weeks.

377. A return of *Winnecke's comet.* (Theoretical elements.)
378. An elliptic orbit; period assigned, 6·67 years.
380. Visible to the naked eye as a star of mag. 2, with a tail 5° long, besides 2 secondary tails.
382. Probably an elliptic comet of long period.
385. A return of *Olbers's comet* of 1815.
386. It had a tail which on April 11 was 5° long. An elliptic orbit: period assigned 1615 years.
387. An apparition of *Encke's comet.*

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
388	307	1888 iii.	July	31	4	160 40	101 26	74 11	0·9025
389	(171)	— iv.	Aug.	19	12	50 56	209 42	11 20	1·7381
390	308	— v.	Sept.	13	0	68 35	137 34	56 24	1·1532
391	309	1889 i.	Jan.	31	6	16 56	357 24	13 38	1·8151
392	310	— ii.	June	13	8	73 31	310 35	16 12	2·2493

ADDITIONAL COMETS

No.	No.	Year.	PP.	d.	h.	π	☊	ι	q
37*a*	26*a*	1457 i.	Jan.	17	23	84 34	249 39	13 16	0·7035
37*b*	26*b*	1457 ii.	Aug.	8	0	9 32	184 24	9 52	0·7606

389. An apparition of *Faye's comet.*

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Wilson	1888, Aug. 7	Brooks	11 weeks.
0·54902	+	......	— Aug. 9	Perrotin	4 months.
1·0	+	Halm	— Oct. 30	Barnard	4 months or +
1·0	—	Berberich	— Sept. 2	Barnard	many months.
1·0	—	Krüger	— Mar. 31	Barnard	4 weeks.
RECENTLY CALCULATED.					
1·0	+	Celoria	1457	Chinese obs.	
1·0	+	Celoria	1457	Chinese obs.	

392. Very faint, say 12th mag.; with a tail 15′ long.

A SUMMARY OF THE PRECEDING CATALOGUE[a].

FROM an examination of the Catalogue just given we may obtain certain results which will here be analysed.

It appears that 394 comet apparitions have been subjected to mathematical investigation, viz.:—

Known periodical comets	23
Subsequent returns	81
Elliptic comets not yet verified, and parabolic comets	284
Hyperbolic comets	6
	394

Of known periodical comets, we have the following, as the number of the apparitions of each:—

24	of Encke's.
17	of Halley's.
8	of Faye's.
6	of Biela's.
5	of Brorsen's.
5	of Winnecke's.
4	of D'Arrest's.
4	of Tuttle's.
3	of Tempel's Ist.
2	of Tempel's IInd.
2	of Tempel's IIIrd.

Also 2 of each of the following:—

961: 1097: 1231: 1264: 1362 i: 1532: 1596: 1678: 1699 i: 1790 iii: 1810: 1812.

Elliptic orbits have been assigned *in the Catalogue* to various comets, of which however no 2[nd] returns have as yet taken place.

Elliptic orbits have been assigned by some computers to certain other comets; of which it must be said that the probability is not sufficiently great to warrant their being included in a list of undoubted elliptic comets.

[a] This summary does not include comets *discovered subsequently* to Dec. 31, 1888.

The following are the known hyperbolic comets:—

1729: 1771: 1774: 1840 i: 1843 ii: 1853 iii.

Hyperbolic orbits have been assigned by some computers to the following comets: but the probability is not sufficiently great to warrant their being definitely given as such:—

1723: 1773: 1779: 1818 iii: 1826 ii: 1830 i: 1843 i: 1844 iii: 1845 i: 1845 ii 1849 iii: 1852 ii: 1863 vi: 1886 ii.

The following are some of those comets which have been supposed to be identical:—

1881 v.	with	1855 ii.
1880 i.	—	1843 i.
1880 iii.	—	1569, 1506, 1444, or 1382.
1873 vii.	—	1818 i.
1871 ii.	—	1827 i.
1863 v.	—	1490.
1860 i.	—	1845 ii, 1785 i, and 1351.
1858 iv.	—	1799 ii.
1857 v.	—	1825 i, and 1790 iii.
1854 iv.	—	1558.
1854 ii.	—	1799 ii.
1853 iv.	—	1582 ii.
1853 i.	—	1664.
1852 ii.	—	1819 ii.
1844 i.	—	1678.
1843 i.	—	1668 and many others.
1840 iv.	—	1490.
1827 iii.	—	1780 i.
1819 iv.	—	1743 i.
1819 iii.	—	1766 ii.
1661	—	1532.

CHAPTER VIII.

A CATALOGUE OF COMETS RECORDED, BUT NOT WITH SUFFICIENT PRECISION TO ENABLE THEIR ORBITS TO BE CALCULATED[a].

IN the present day it does not often happen that a comet becomes visible without its being observed sufficiently long for at any rate some approximation to the elements of its orbit to be deduced. Such however was not the case in olden times. Observers were few, and till the 17th century observatories and instruments can scarcely be said to have existed at all. Therefore whatever astronomical information we possess antecedent to A.D. 1600, we owe to the writings of historians and chroniclers, who seldom give more than bare statements, with few or no details.

The first astronomer who made any systematic attempt to put together the various allusions to comets which occur in the old writers was Stanislaus Lubienitzki, whose *Theatrum Cometicum* in 2 folio volumes appeared at Amsterdam in 1668. The 2nd volume contains records of 415 comets or supposed comets up to 1665. Hevelius gives a history of comets in the XIIth Book of his *Cometographia*. Far more critical is Nicolas Struyck, who in his *Algemeene Geographie*, published at Amsterdam in 1740, and in his *Vervolg van de Beschryving der Staartsterren*, published at Amsterdam in 1753, paved the way for the French astronomer Pingré, who in 1783 published his celebrated *Cométographie; ou*

[a] I should be glad to receive information calculated to render this chapter more complete. I cannot but believe that a diligent search through the journals, whether published or in MS., of modern travellers and others, would bring to light many more comets than these catalogued in this volume.

Traité historique et théoretique des Comètes. This work, which for the industry and labour bestowed upon it has few equals, has been from the period of its publication down to the present day the astronomer's text-book on the subject of cometary history: it has never been superseded, and is never likely to be, though supplementary matter has of course been accumulated. E. Biot, working from Chinese sources, followed up Pingré with great industry. The following catalogue is based upon that of Pingré, and includes recent results, especially those elaborated in a valuable catalogue commenced by Hind in the *Companion to the Almanac*, 1859 and 1860, but remaining unfinished. Brevity being essential to this work, I have been obliged to omit much that was curious and interesting, and to confine my attention chiefly to necessary facts and figures, with references only to the most important authorities.

The Chinese observations, to which such constant reference is made, were originally made known in Europe by MM. Couplet, Gaubil, and De Mailla, Jesuit priests at Pekin, early in the 18th century, who made very good use of their opportunities of benefiting science. De Mailla's MSS. were published at Paris in the last century, but those of Gaubil and Couplet remain in their original form. E. Biot published in the *Connaissance des Temps* a translation of some valuable Chinese catalogues of comets[b], which have been duly consulted; and it is not improbable that as our intercourse with that remarkable people becomes greater, further sources of information may be opened to us.

Biot gives 2 supplementary catalogues of "extraordinary stars." These are distinct in the originals from the comets strictly so called; but as there is little doubt that many of these objects were genuine comets, though not treated as such by the Chinese, a selection of them is inserted in this catalogue, an asterisk (*) being appended either to the year or to M. Biot's name. The remainder will be given in a catalogue of "New Stars," in a later volume of this work, where will also be found some further remarks on these objects.

[b] 1846, pp. 44–84.

The most recent editor of Chinese comet observations is the late Mr. J. Williams, whose catalogue published in 1871 is by far the most elaborate work of its sort extant. Great use has been made of that valuable compilation in the revision of the pages which now follow.

It may be well to state that very great uncertainty hangs over the earlier comets, hereinafter referred to, and to some extent, too, over all, more especially as regards the positions in which they were seen and the duration of their visibility.

The Chinese constellations are much more numerous than ours, and where several Greek letters precede a Latin genitive case, it is to be understood that the Chinese place the comet in the group formed of those stars without specifying that it was in juxtaposition with any one star in particular.

The Chinese reckon by moons, and as it rarely happens that the whole of a lunation is comprised in a single Julian month, it is requisite in many cases to couple 2 months together: thus, May—June, which means that the comet appeared in the "moon" which began on (say) May 18, and therefore ended on June 15. In cases where the precise day of the lunation is recorded, the exact Julian day can of course be deduced, and the expedient of coupling together 2 months is superseded. The years B.C. are reckoned in astronomical style.

One *tchang* equals 10°; one *che* equals 1°.

[1.] B.C. **1770.** ± St. Augustine has preserved the following extract from Varro:—"There was seen a wonderful prodigy in the heavens with regard to the brilliant star Venus, which Plautus and Homer, each in his own language, call the 'Evening Star.' Castor avers that this fine star changed colour, size, figure, and path: that it was never seen before, and has never been seen since. Adrastus of Cyzicus and Dion the Neapolitan refer the appearance of this great prodigy to the reign of Ogyges."—(*De Civitate*, xxi. 8.) This description, such as it is, may be that of a comet, but no further particulars have been preserved.

[2.] **1194.** ± We are told by Hyginus, a contemporary of Ovid, that "on the fall of Troy, Electra, one of the Pleiads, quitted the company of her 6 sisters, and passed along the heavens toward the Arctic Pole, where she remained visible in tears and with dishevelled hair, to which the name of 'comet' is applied."—(Fréret, *Acad. des Inscriptions*, x. 357.) What we are to understand by this is doubtful, but the account might relate to a comet which passed from Taurus to the North Pole.

[3.] **1140.** ± At the time that Nebuchadnezzar overran Elam "a comet arose whose body was bright like the day, while from its luminous body a tail extended, like the sting of a scorpion."—(A. H. Sayce, *Babylonian Inscriptions.*)

[4.] **975.** ± "The Egyptians and the Æthiopians felt the dire effects of this comet, to which Typhon, who reigned then, gave his name. It appeared all on fire, and was twisted in the form of a wreath, and had a hideous aspect; it was not so much a star as a knot of fire."—(Pliny, *Hist. Nat.*, ii. 25.) *Date* very uncertain.

[5.] **619** or **618.** "We shall see in the W. a star such as is called a comet; it will announce to men war, famine, and the death of several distinguished leaders."—(*Sybill. Orac.* iii.) Though given as a prophecy, Pingré says he feels justified in citing this passage as a historical record. He thinks moreover that the prophet Jeremiah may refer to a comet, and it might be this comet, in *Jer.* i.

[6.] **611.** In July a comet appeared among the 7 stars of Ursa Major.—(Confucius, *Tchun-tsieou*, quoted by Ma-tuoan-lin.)

[7.] **532** or **531.** At the winter solstice a comet appeared in the Western part of Aquarius, or the tail of Capricornus.—(Gaubil.) Ma-tuoan-lin gives, from Confucius, 531 as the date, and the position σ, α, τ Scorpii. Pingré regards the description as applying to one and the same comet.

[8.] **524–23.** In the winter a comet passed from Scorpio to the Milky Way.—(Gaubil; De Mailla, *Histoire Générale de la Chine*, ii. 193.)

[9.] **515.** In July a comet was seen near H Herculis. (Williams, 1.) Monck suggests that this should read η Herculis.

[10.] **501.** In December a comet was seen in the East. (Williams, 1.)

[11.] **481.** A comet appeared at the end of the year in the E. part of the heavens. Its length was 2°, and it reached from the star *Yng* (?) to α Scorpii.—(Gaubil; Ma-tuoan-lin; De Mailla, ii. 222.)

[12.] **479.** At the time of the battle of Salamis a comet in the shape of a horn was visible.—(Pliny, *Hist. Nat.*, ii. 25.)

[13.] **465.** ± During a period of 75 days an extraordinary object appeared in the sky, according to the testimony of several writers.—(Damachus; Pliny, *Hist. Nat.*, ii. 58.) A comet may be referred to, but an Aurora Borealis would seem best to reconcile the various European statements. Ma-tuoan-lin speaks of a comet in 466, which Pingré considers identical with the "extraordinary object" of the European writers visible in January or February 465.

[14.] **432.** It is certain that a comet appeared in this year.—(Couplet; De Mailla, ii. 244; Ma-tuoan-lin.)

[15.] **426** *or* **402.** At the time of the winter solstice, during the archonship of Euclides, at Athens, a comet appeared near the North Pole.—(Aristot., *Meteor.*, i. 6.) There were 2 archons of this name, it is therefore impossible to fix the year of this comet's apparition.

[16.] **360.** A comet was seen in China and Japan in the W.—(Couplet; De Mailla, ii. 267; Kaempfer, *Histoire du Japon*, ii. La Haie, 1729.)

[17.] **345** (?). A comet in the form of a mane was seen, which was afterwards changed into that of a spear.—(Pliny, *Hist. Nat.*, ii. 25.) Date very uncertain; Pliny gives the double date of the Olympiad and A. U. C., which do not correspond, so one or the other must be wrong. 345 above is from Pingré.

[18.] **344.** "On the departure of the expedition of Timoleon from Corinth for Sicily the gods announced his success and future greatness by an extraordinary prodigy. A burning torch appeared in the heavens for an entire night, and went before the fleet to Sicily."—(Diodorus Siculus, *Bibliotheca Historica*, xvi. 11; Plutarch, *Timoleon*.) Pingré remarks that it is easy to see that the comet appeared in the W., and had a considerable N. declination.

[19.] **340.** A comet was seen for a few days near the equinoctial circle.—(Aristotle, *Meteor.*, i. 7.)

[20.] **304.** A comet was seen in China.—(Ma-tuoan-lin; De Mailla, ii. 306.)

[21.] **302.** A comet was seen in China.—(Ma-tuoan-lin; De Mailla, ii. 306.) The Chinese annalist expressly says that there were 2 comets in 2 years.

[22.] **295.** A comet was seen in China.—(Ma-tuoan-lin.)

[23.] **239.** A comet was seen in China. It came from the E., and passed by the N., and in the 5th moon (May) it was seen during 16 days in the W.—(Ma-tuoan-lin; Williams, 2.)

[24.] **237.** In the 9th year of Chi-hoang-ti a star appeared in the horizon. In April it was seen in the W.; it appeared then in the N., to the S. of the 7 stars of Ursa Major, for 80 days.—(Ma-tuoan-lin; Williams, 2.)

[25.] **233.** In China a comet was seen in January in the E.—(Ma-tuoan-lin.)

[26.] **232.** Four comets were seen during 80 days.—(Williams, 3.)

[27.] **213.** A brilliant star was seen in China to come from the W.—(Ma-tuoan-lin; De Mailla, ii. 399.) Probably a comet.

[28.] **203.** A torch extended from E. to W. for 10 days in Aug.—Sept. It appeared near Arcturus.—(Julius Obsequens, *Prodigiorum Liber*, 8vo. Amstelodami, 1679, Supplement by Lycosthenes; Ma-tuoan-lin.)

[29.] **202.** A burning torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, Suppl.)

[30.] **171.** A large comet with a tail was seen in China at the end of the summer.—(Couplet; De Mailla, ii. 554.)

[31.] **168.** A torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, Suppl.; Livius, *Historia*, xliii. 13.)

[32.] **166.** A burning torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, Suppl.)

[33.] **165.** A torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, Suppl.) We are further told that at one place the Sun was seen for several hours in the night, so that if this object was a comet it must have been an extremely brilliant one.

[34.] **156.** In October (end of) a comet 10° long appeared in the W. It was visible for 16 days, and traversed Aquarius and Equuleus to the neck of Pegasus.—(Ma-tuoan-lin; De Mailla, ii. 568.)

[35.] **154** (i). A comet came from the S. W. in January.—(Ma-tuoan-lin; De Mailla, ii. 569.)

[36.] **154** (ii). In July a comet appeared in the N. E.—(De Mailla, ii. 569; Williams, 4.)

[37.] **153.** In February a tailed star appeared in the W.—De Mailla, ii. 571; Williams, 4.)

[38.] **147.** A comet appeared in May in the N. W., and lasted 2 or 3 weeks. It had the same R. A. as Orion.—(Ma-tuoan-lin; De Mailla, ii. 588.)

[39.] **146** (i). On March 14 a comet 10 cubits long was seen at night in the N. W., probably in Orion. As it passed on it increased but little in size. After 15 days it was no more seen.—(Williams, 4.)

[40.] **146** (ii). "After the death of Demetrius king of Syria, the father of Demetrius and Antiochus, a little before the war in Achaia, there appeared a comet as large as the Sun. Its disc was at first red, and like fire, spreading sufficient light to dissipate the darkness of night; after a little while its size diminished, its brilliancy became weakened, and at length it entirely disappeared."—(Seneca, *Quæst. Nat.*, vii. 15.) It lasted 32 days.—(Julius Obsequens, *Prodigiorum Liber.*) Probably this account relates to the comet seen this year in China, August 6–16, and which passed from the divisions Scorpio and Sagittarius to near ζ Ophiuchi. The size of the Chinese comet steadily decreased day by day.—(Williams, 4.)

[41.] **146** (iii). In October a comet was seen in the N. W.—(Williams, 5.)

[42.] **137** (i). "In the reign of Attalus a comet was seen which, small at first, afterwards became much larger. It reached the equinoctial circle, and equalled in length that part of the heavens which is called the Milky Way."—(Seneca, *Quæst.*

Nat., vii. 15.) It appeared in March—April, in the lower part of Hydra, and passed through Leo—Virgo into the circumpolar regions, arriving at length at the Milky Way. —(Ma-tuoan-lin.)

[43.] **137** (ii). A comet appeared 2 months after the preceding; it passed from θ, ϵ Herculis to α, ϵ, ζ Lyræ.—(Ma-tuoan-lin.)

137 (iii). In August a comet was seen in the N. E.—(Williams, 5; Ma-tuoan-lin; De Mailla, iii. 9.)

The preceding 3 comets may in reality have been but one and the same; one of them, or else the comet of 134 (*post*), is the comet which appears in the other catalogue under the date of 136. [*Therefore a number is dropped here.*]

[44.] **136** (ii). In October a comet was seen in the N. E.—(Williams, 5.)

[45.] **134.** At the birth of Mithridates a comet appeared and lasted 70 days; the heavens appeared all on fire; the comet occupied the fourth part of the sky, and its brilliancy was superior to that of the Sun; it took 4 hours to rise and 4 to set.—(Justinus, *De Historicis Philippicis*, xxxvii. 2.) There is very great uncertainty about this comet of Mithridates, but Pingré, after weighing Ma-tuoan-lin's account, considered that 134 was certainly the year. He also says that probably it appeared in the W. in the middle of July; before the end of August it would have been lost for a few days in the Sun's rays, when probably the Perihelion Passage took place; it would then have re-appeared with increased brilliancy early in September in the E. (for 30 days?), and so have passed away from the Sun.—(*Comét.* i. 270, 578.) Ma-tuoan-lin (Williams, 6) would have us consider the comet of September 134 to be different from the comet of July 134, but this does not at all follow.

[46.] **127.** A burning torch appeared in the heavens.—(Julius Obsequens, *Prodig.* Suppl.)

[47.] **119.** In the spring in China a comet was seen in the E.—(De Mailla, iii. 46.)

[48.] **118.** When Mithridates ascended the throne there appeared during 70 days a comet exactly resembling that which was seen at the birth of that monarch.—(Justinus, *De Historicis Philippicis*, xxxvii. 2.) It came from the N. W. in May.—(Ma-tuoan-lin; Williams, 6.)

[49.] **109** (i). In June a comet was seen in the feet of Gemini.—(Ma-tuoan-lin; De Mailla, iii. 61.)

[50.] **109** (ii). This comet appeared contemporaneously with the preceding: it was in Ursa Major, near κ, λ, ξ.—(Ma-tuoan-lin; De Mailla, iii. 61.)

[51.] **108.** A comet appeared in the region lying between Procyon (α Canis Minoris) and α and β Geminorum.—(Ma-tuoan-lin.) Or in the year 107; place uncertain.—(Williams, 6.)

[52.] **102.** ± A comet was seen in China near γ Bootis.—(Ma-tuoan-lin.)

[53.] **93.** A torch appeared in the heavens.—(Julius Obsequens, *Prodig.*)

[54.] **91.** A torch appeared in the heavens.—(Julius Obsequens, *Prodig.*)

[55.] **86.** In August a comet was seen in the E.—(De Mailla, iii. 98; Williams, 7; Pliny, *Hist. Nat.*, ii. 25.) Pliny's is merely an incidental notice. He says that comets foretell bloodshed, and gives as an instance the one which appeared during the consulate of Octavius.

[56.] **83.** In March a comet was seen in the N. W.—(De Mailla, iii. 101; Williams, 7.)

[57.] **75.** "In the consulate of Cn. Octavius and C. Scribonius a spark was seen to fall from a star; it grew larger as it approached the Earth, and became equal in size to the Moon, and gave as much light as the Sun gives during the day-time when the sky is entirely covered. On returning into the heavens it took the form of a *lampas* [torch, one of Pliny's names for a class of comets]."—(Pliny, *Hist. Nat.*, ii. 35.) The above is a rather obscure explanation, but in Pingré's estimation a comet fairly meets it. In May a bright star was seen in the sidereal divisions of β Andromedæ and β Arietis.—(Williams, 7.)

[58.] **72.** On May 10, early in the evening, a tailed star appeared to the W. of the sidereal division of α, β, &c. Orionis.—(Williams, 7.)

[59.] **71.** On August 20 a comet appeared in the sidereal division of α Crateris.—(Williams, 8.)

[60.] **69.** On August 4 a comet appeared in the sidereal division of α Crateris; it passed near the Moon.—(Williams, 8.) Can this and the previous comet be one and the same?

[61.] **68** (i). In January—February a comet was seen in the W.—(Williams, 8.)

[62.] **62.** A burning beam stretched from the western horizon to the zenith.—(Julius Obsequens, *Prodig.*) Torches ran from the W. to the middle of the sky.—(Dion Cassius, *Hist. Roman.*, xxxix.) A comet appeared in the E. in the 6th moon.—(De Mailla, iii. 136.) Dion Cassius's allusion is very doubtful; and whatever may really have been the date of the burning beam, it is believed that De Mailla's comet must be referred to 61, his dates invariably being 1 year behind. [But see the next paragraph.]

[63.] **60.** In July a comet was seen in the E.—(Williams, 8.) Perhaps this and De Mailla's comet of 62 or 61 are identical.

[64.] **55.** A torch appeared which advanced from the S. to the N.—(Dion Cassius, *Hist. Roman.*, xxxix.)

[65.] **52.** A torch appeared, which passed from the S. to the E.—(Dion Cassius, *Hist. Roman.*, xl.)

[66.] **48.** During the war between Cæsar and Pompey "a comet, that terrible star which upsets the powers of the Earth, shewed its portentous hair."—(Lucanus, *Pharsalia*, i. 529.) In April a long comet was seen near β Cassiopeiæ; passing by ι in that constellation, it became lost in the circumpolar regions.—(De Mailla, iii. 155.) In March an extraordinary star shewed itself about 9° to the N. E. of α, β, γ, η Cassiopeiæ: it was 10° long, and pointed to the W. It passed by ν, ξ, o, π Cassiopeiæ, and went towards the "blue palace" [circle of perpetual apparition at 34° lat. N.]—(Biot.*)

[67.] **47.*** In April—May an extraordinary star, as large as a scourge, was seen: it was 4° or so to the E. of μ Sagittarii.—(Biot.)

[68.] **46.** In June an extraordinary star was seen in the sidereal division of the Pleiades, 5° E. of ν Persei. Its tail was $\frac{3}{10}$ of a cubit long.—(Biot*; Williams, 9.)

[69.] **43** (i). In May—June a comet was seen in China, whose R. A. was the same as that of Orion.—(De Mailla, iii. 162.) It was in the N. E., and its tail, which was 8 cubits long, and afterwards longer, pointed to the sidereal division of α, β Orionis.—(Williams, 9.)

[70.] **43** (ii). A hairy star was seen for 7 days under the Great Bear during the celebration of the games given by the Emperor Augustus in honour of Venus. It rose at about 5 in the evening, was very brilliant, and was seen in all parts of the Earth. The common people supposed that the star indicated the admission of the soul of Julius Cæsar into the ranks of the immortal gods.—(Suetonius, *Vita Julii Cæsaris*, lxxxvii.) It was visible therefore from Sept. 23 to Sept. 29. Dion Cassius says, that, in addition to the comet, which appeared contemporaneously with the Emperor's games, there was seen a burning torch, which traversed the heavens from E. to W.; and also an unknown star, which shone for many days.—(*Hist. Roman.* xlv. 17.) Pingré thinks that the "torch" was simply a meteor, but that the "unknown star" was the preceding object which was seen in China, and there recorded as a comet.—*Comét.* i. 278.)

[71.] **42** *and* **44.** Previous to the battle of Philippi comets appeared.—(Virgil, *Georgica*, i. 488; Manilius, *Astronomicon*, i. 907.) Perhaps a comet in each year.

[72.] **31.** A torch appeared for several days.—(Dion Cassius, *Hist. Roman.*, l.) In February a comet 60 or 70 cubits (? degrees) long was seen in the sidereal division of α Pegasi.—(De Mailla, iii. 178; Ma-tuoan-lin; Williams, 9.)

[73.] 29. Before Egypt submitted to Augustus there appeared comets.—(Dion Cassius, *Hist. Roman.*, li.) Lubienitz says that a comet appeared for 95 days in Libra, but he gives no authority.

[74.] 4. In March a comet appeared for 70 days in the sidereal division of α, β, &c. Capricorni.—De Mailla, iii. 214; Williams, 10.)

[75.] 3 B.C. In April or May a comet appeared near α and β Aquilae.—(De Mailla, iii. 214; Williams, 10.)

[76.] 10 A.D. Several comets visible at the same time.—Dion Cassius, *Hist. Roman.*, lvi. 24.) Some modern cometographers state that a comet appeared in Aries for 32 days.—(Lubienitz.)

[77.] 14. Hairy stars of the colour of blood.—(Dion Cassius, *Hist. Roman.*, lvi. 29.) A comet was seen in China for 20 days, either at the end of 13 or the beginning of 14.—(De Mailla, iii. 140; Williams. 10.)

[78.] 19. A comet was seen in China.—(Couplet.)

[79.] 22. In November—December a comet was seen for 5 days. It was in the sidereal division of κ, λ Hydræ, and moved in a S. E. direction.—(De Mailla, iii. 251; Ma-tuoan-lin; Williams, 11.)

[80.] 39. On March 13 a comet became visible in the Pleiades; it moved in a N. W. direction towards α, β and λ, μ Pegasi, and remained in sight for 40 days.—(De Mailla, iii. 326; Ma-tuoan-lin; Williams, 11.)

[81.] 54. In the autumn (?) a comet appeared for a long time. It was first seen in the N.; it moved to the zenith, and thence Eastwards, and day by day diminished in brilliancy.—Dion Cassius, *Hist. Roman.*, lx. 35; Suetonius, *Vita Claudii.*) It appeared in the circumpolar regions.—(De Mailla, iii. 345.) Probably De Mailla's reference is to the next comet.

[82.] 55 (i). On June 4 a comet appeared; the planet Mercury was about 20° in the E. part of the sidereal division γ, ε, &c. Geminorum. The comet pointed to the S.E., was bright, and 10 cubits long. It went to the N. E., passing above the W. boundary of the circle of perpetual apparition. It lasted 31 days.—(Williams, 11.)

[83.] 55 (ii). In November a comet appeared which remained visible for 16 weeks, or till March 56. When first seen it was 2° long, and was then moving towards the S. W. It disappeared on March 26, 6° N. E. of γ, δ, η, θ Cancri.—(Gaubil; Biot.*)

[84.] 60. On Aug. 9 a comet, with a tail 2 cubits long, appeared to the N. of η, γ, α, δ Persei. It remained visible for 19 weeks or more, and, passing Southwards, disappeared S. of the feet of Virgo.—(Tacitus, *Annales*, xiv. 22; De Mailla, iii. 352; Ma-tuoan-lin; Williams, 11.)

[85.] 61. On Sept. 27 a strange star was detected to the N. W. of ρ, δ Boötis, with a tail pointing towards Corona Borealis. After 17 days it quitted this position, but we are not told whither it went. It was visible for 10 weeks altogether.—(Ma-tuoan-lin; Biot*; Seneca, *Quæst. Nat.*, vii. 28; Williams, 12.) It is uncertain whether the comet seen in China is the same as that spoken of by Seneca.

[86.] 64 (i). On May 3 an extraordinary star, with a vapour 2° long, was seen to the S. of η Virginis; it lasted 11 weeks.—(Gaubil; Biot.*)

[87.] 64. (ii). At the end of the year, in the reign of Nero, a comet appeared for 6 months. It passed from the N. through the W. to the S.—(Seneca, *Quæst. Nat.*, vii. 21, 29; Tac., *Ann.*, xv. 47; Suetonius, *Vita Neronis.*)

[87.] 65. On June 4 a great star was observed in the sidereal divisions of δ and ν Hydræ; it approached near α and γ Leonis, and passing α, γ, δ Persei arrived in the vicinity of β Leonis. The vapour extended to ι and κ Ursæ Majoris; it remained visible 8 weeks.—(Ma-tuoan-lin; Williams, 12.)

[89.] 69. Sometime between April and December a comet appeared.—(Dion Cassius, *Hist. Roman.*, lxv. 8.) Possibly this may be the object referred to by Josephus as having been seen suspended over Jerusalem before its destruction by Titus.—(*Bella Judæorum*, vi. 5.)

[90.] **70.** In December 70 or January 71 a strange star appeared in α, γ, ϵ, η, ζ Leonis for 7 weeks.—(Gaubil; Biot.*)

[91.] **71.** On March 6 a comet appeared in the sidereal division of the Pleiades; after 8 weeks it was seen near α, γ, &c. Leonis, and disappeared to the right of the sidereal division of α Virginis.—(Gaubil; Biot*; Williams, 12.)

[92.] **75.** On July 14 a comet was discovered in the sidereal division of α Hydræ; its tail was 3 cubits long. Moving to the S. of Coma Berenicis it passed to the vicinity of β Leonis.—(De Mailla, iii. 375; Williams, 13.)

[93.] **76.** On August 9 a comet, with a tail 2 or 3 cubits long, was seen between α Herculis and α Ophiuchi, whence it passed to the sidereal division of α and β Capricorni. It remained visible for 6 weeks, and travelled slowly.—(De Mailla, iii. 376; Ma-tuoan-lin; Pliny, *Hist. Nat.*, ii. 25; Williams, 13.)

[94.] **77.** On Jan. 23 a comet, with a tail 8 or 9 cubits long, appeared in the R. A. of Aries, whence it moved towards the tail of Draco and the N. Pole. It remained visible for 15 weeks.—(Ma-tuoan-lin; Gaubil; Williams, 13.)

[95.] **79.** In the spring (?) a comet was visible for a long time during the illness of Vespasian.—(Dion Cassius, *Hist. Roman.*, lxvi. 17; Suetonius, *Vita Vespasiani.*)

[96.] **84.** On May 25 an extraordinary star, 3 cubits long, appeared in the morning in the Eastern heavens. It was in the 8th degree of the sidereal division of μ^2 Scorpii. It traversed ν, ξ, o, π Cassiopeiæ into the circle of perpetual apparition, remaining visible for 6 weeks.—(Biot*; Williams, 13.) Williams places the comet in the 8th degree of the division of α Muscæ. These two divisions are in the original Chinese represented by words of nearly identical sound: hence the uncertainty.

[97.] **102.** On the evening of Jan. 7, a greenish white vapour, 30 cubits long, was seen. It extended from ι, κ, χ, ϕ Eridani towards β Canis Majoris, and was visible for 10 days.—(Williams, 13)

[98.] **104.*** On June 10 a new star appeared in the circumpolar regions; it passed to the Pleiades, and vanished in the next moon.—(Biot.)

[99.] **108.*** On July 25 an extraordinary star appeared in Ursa Major, with a tail 2° long, which extended in a S.W. direction towards κ and ι of that constellation.—(Biot.)

[100.] **110.** In January a comet rose to the S. W. of γ, δ, ϵ and ζ Eridani. It had a bluish tail, 6 or 7 cubits long, pointing to the N. E., in which direction (?) it moved.—(Ma-tuoan-lin; Williams, 14.)

[101.] **115.** On Nov. 16 an extraordinary star appeared in the W. On the 21st it was to the S. of β and α Aquarii, and afterwards moved to Musca and the Pleiades.—(Biot.*) Gaubil erronously refers this comet to 117.—(Hind, *Companion to the Almanac*, 1859, p. 12.) Pingré, following Gaubil, reads "β Aquarii and α Equulei."

[102.] **132.** On January 29 a strange star, with a tail 2° long, pointing towards the S.W., was observed. Its R. A. was 6° greater than that of β Capricorni; it was also seen near δ, λ, ϕ Sagittarii, and moved near β Aquarii, α Equulei, and α Aquarii, towards ϵ and θ Pegasi.—(Ma-tuoan-lin; Biot*; Williams, 14.) This comet was seen in Europe in the time of Adrian, whose courtiers told him that the soul of Antinous had been changed into a new star.—(Dion Cassius, *Hist. Roman.*, lxix.) Williams's date is 131 (no month), and his places less precise.

[103.] **133.*** On February 8 an extraordinary star, with a vapour 50° long and 2° broad, was seen to the S.W. of γ, δ, ϵ, &c. Eridani.—(Biot.)

[104.] **149.** On Oct 19 a comet, with a tail 5 cubits long, was observed in the head of Hercules; it was only seen for 3 days.—(De Mailla, iii. 441; Williams, 15.) Gaubil dates its appearance for 148, and Ma-tuoan-lin for 147, but it can be shown by an extraneous circumstance that 149 was really the year.

[105.] **161** (i). In February—March a comet was seen near α Scorpii.—(De Mailla, iii. 459.)

[106.] **161** (ii). On June 14 an extraordinary star appeared in the sidereal division of α Pegasi. It remained nearly stationary for some time, and then retrograded; and when it reached the R. A. of $14\frac{1}{2}^h$ it threw out a tail 5 cubits long.—(Ma-tuoan-lin; Williams, 15.)

[107.] 180 (i). In Aug.—Sept. a comet was discovered near ι, κ, λ, μ, ν, ξ Ursæ Majoris. It moved E. to the tail of Leo, and lasted 3 weeks.—(Ma-tuoan-lin.)

[108.] 180 (ii). A comet was visible in the winter of 180–1 for 2 or 3 months. It came from the E. of Sirius, and moved towards κ, υ, λ Hydræ, where it vanished.—(De Mailla, iii. 506; Ma-tuoan-lin; Williams, 16.)

[109.] 182 (i). In February, March, or April, a comet was seen near δ Andromedæ. It tended towards the E., and entered the circle of perpetual apparition, but left it again after 3 days. It was visible for nearly 9 weeks.—(Ma-tuoan-lin.)

[110.] 182 (ii). In August—September a comet appeared near ι and κ Ursæ Majoris, which was also seen in the vicinity of β Leonis.—(De Mailla, iii. 507; Ma-tuoan-lin; Williams, 16.)

[111.] 188 (i). In March—April a comet was observed in the sidereal division of β Andromedæ. It went the contrary way and became circumpolar, and lasted about 8 weeks.—(De Mailla, iii. 520; Williams, 17.)

[112.] 188 (ii). On July 29 an extraordinary star appeared in Corona Borealis; it moved to the S.W. to α Herculis and α Ophiuchi. It disappeared in the division of μ^2 Scorpii.—(Williams, 17.) Biot dates this comet for June 30, 182.

[113.] 190.± During the reign of Commodus a hairy star was seen.—(Ælius Lampridius; Herodianus, *Historia*, i.) No more exact date can be assigned.

[114.] 192. In September—October (or October—November) a grand comet 100 cubits long was seen to the S. of the sidereal divisions of α and κ Virginis.—(Ma-tuoan-lin; Williams, 17.)

[115.] 193. In November—December a comet was seen near α and ζ Virginis, moving towards the N. E. On arriving in the region near α Herculis and α Ophiuchi it disappeared.—(Ma-tuoan-lin; Williams, 18.) Another authority places it near α Herculis, &c. at its discovery.—(De Mailla, iii. 363.)

[116.] 200. On Nov. 7 a comet was observed near δ Serpentis.—(De Mailla, iv. 35; Ma-tuoan-lin; Williams, 18.)

[117.] 204. In November—December a comet appeared in the sidereal division of μ Geminorum, which passed by θ, γ, δ Cancri, α, γ Leonis, to the region lying around β Leonis.—(De Mailla, iv. 40; Ma-tuoan-lin; Dion Cassius, *Hist. Roman.*, lxxv. 16; Williams, 18.)

[118.] 206. In February a comet was observed in the square of Ursa Major: the tail extended over the whole of the circle of perpetual apparition: it reached to Ursa Minor.—(De Mailla, iv. 43; Ma-tuoan-lin; Williams, 18.)

[119.] 207. On Nov. 10 a comet appeared in the sign of Leo (or Virgo).—(Ma-tuoan-lin; Couplet; Williams, 18.) De Mailla assigns this comet to the previous year.—(*Hist. Gén.*, iv. 45.)

[120.] 213. In January—February a comet appeared near θ, υ, ϕ Geminorum.—(De Mailla, iv. 63; Williams, 19.)

[121.] 222. On Nov. 4 a new star was observed between β Virginis and σ Leonis.—(Gaubil.) It is uncertain whether this was a comet or a temporary star. Either will accord with the description. Between η and γ Virginis.—(Biot*; Williams, 20.)

[122.] 225. On Dec. 9 a comet was discovered near *m* Leonis; it passed by α, γ Leonis.—(Ma-tuoan-lin; Williams, 20.)

[123.] 232. On Dec. 4 a comet was seen near σ Leonis. It approached β Leonis.—(Ma-tuoan-lin.) Near γ Virginis.—(Williams, 20.)

[124.] 236 (i). On Nov. 30 a comet, with a tail 3 cubits long, was seen near α Scorpii; on Dec. 1 it (or another comet) was seen in the E.—(Ma-tuoan-lin; Gaubil; Williams, 20.)

[125.] 236 (ii). On Dec. 15 a comet was seen; it approached *e*, *f* Ophiuchi and θ, ζ Herculis.—(Ma-tuoan-lin; Gaubil.) Williams treats this comet and the preceding as one, and it appears probable that such was the case.

[126.] 238 (i). In September a comet, with a tail 3 cubits long, was discovered in the sidereal division of κ, λ Hydræ; it moved eastwards (?), and disappeared in 6 weeks.—(Gaubil; Ma-tuoan-lin; Williams, 21.)

[127.] 238 (ii). An extraordinary star was visible from Nov. 29 to Dec. 15. On the former day it was between π Cygni, κ Andromedæ, and λ, μ (or τ, υ) Pegasi. On Dec. 10 it passed near *h*, *g* Tauri Poniatowskii and γ Ophiuchi.—(Gaubil; Biot*; Williams, 21.)

[128.] 245. On Sept. 18 a comet, with a tail 2 cubits long, appeared in the sidereal division of α Hydræ; it moved towards the division of υ Hydræ; it was visible for 3 weeks.—(Gaubil; Ma-tuoan-lin; Williams, 21.)

[129.] 247. On Jan. 16 a comet, with a tail 1 cubit long, was observed: it had the same R.A. as Corvus, and was visible for 56 days.—(Ma-tuoan-lin.) One authority states that the comet was visible for 156 days.—(Williams, 22.)

[130.] 248 (i). In April—May a comet was seen in the Pleiades. Its tail was 6 cubits long, and extended towards the S.W.—(Ma-tuoan-lin.)

[131.] 248 (ii). In August a comet appeared in the sidereal division of α Crateris; it moved towards that of γ Corvi. The tail was 2° long, and the comet remained visible for 6 weeks.—(Ma-tuoan-lin.) Williams (p. 22) treats the two preceding comets as one.

[132.] 251. On Dec. 21 a comet appeared in the sidereal division of α and β Pegasi. It moved westwards, and disappeared after 13 weeks.—(Ma-tuoan-lin; Williams, 22.)

[133.] 252. On March 25 a comet was observed in the sidereal division of Musca, with a tail 50 or 60 cubits stretching towards the S. in the direction of the cross of Orion (δ, ε, &c.). The comet was seen for 3 weeks.—(Gaubil; Ma-tuoan-lin; (Williams, 22.)

[134.] 253. In December a comet appeared near η Virginis, γ, δ, ε Corvi, and afterwards near β Leonis. The tail pointed to the S.W., and was fifty cubits long. It remained visible for 6 months.—(Ma-tuoan-lin; Williams, 22.) Hind remarks that probably the comet's motion was retrograde, and that therefore it receded from the Sun's place towards the W.; also that its path was no doubt more extensive than Ma-tuoan-lin has set down.—(*Companion to the Almanac*, 1859, p. 19.)

[135.] 254. In December a vapour emerged from near δ Sagittarii. Its length is stated to have been very great.—(Ma-tuoan-lin.) Pingré seems to doubt whether this was a comet or not.

[136.] 255. In January—February a comet was seen near ε, ζ Aquilæ, to the N.W., near the horizon.—(Ma-tuoan-lin; Williams, 23.)

[137.] 257. In November or December a white comet was seen in the sidereal division of α Virginis.—(Ma-tuoan-lin; Williams, 23.)

[138.] 259. On November 23 a strange star was seen near β Leonis. It moved towards the S.E., traversed the division of γ Corvi, and disappeared in a week.—(Biot*; Williams, 23.)

[139.] 262. On Dec. 2 a comet, with a tail 50° long, appeared in the sidereal division of κ, ι Virginis. It moved towards the N., and was visible for 6 weeks.—(Gaubil.) Ma-tuoan-lin says that its tail was only 5 tsun ($\frac{5}{10}$ of a cubit) long.—(Williams, 23.)

[140.] 265. In June a comet was seen near α, β, η Cassiopeiæ. Its tail was 10 cubits long, and pointed to the S.E., and after 12 days it disappeared.—(Ma-tuoan-lin; Williams, 23.)

(141.] 268. On Feb. 18 a comet was seen in the sidereal division of β Corvi. It advanced to the N.W., and subsequently turned towards the E. (Ma-tuoan-lin; Williams, 24); which remark probably has reference only to the tail.—(Hind.)

[142.] 269. In October—November a comet was seen within the circle of perpetual apparition.—(De Mailla, iv. 148.)

[143.] 275. In January—February a comet was discovered in the sidereal division of β Corvi.—(Ma-tuoan-lin; Williams, 24.)

[144.] 276. A comet was visible from June 23 to September. It moved from the sidereal division of α Libræ, by α Boötis to β Leonis, and passing through the sidereal division of α Crateris, attained to the square of Ursa Major and ι, κ, λ, μ Ursæ Majoris.—(Ma-tuoan-lin; Williams, 24.) Hind suggests that the Chinese account may fairly be considered as applying to the motion of the head (which was therefore retrograde) and the direction of the tail of *one* comet, though Ma-tuoan-lin states that there were *three.* "If Ma-tuoan-lin had been more precise in his dates, we might have approximated to the elements of the real orbit."—(*Companion to the Almanac*, 1859, p. 20.)

[145.] 277 (i). Ma-tuoan-lin (Williams, 24) says that in January—February there was a comet in the W., and in April—May another in the sidereal division of Musca, which two are probably identical.—(Hind, *Companion to the Almanac*, 1859, p. 20.)

[146.] 277 (ii). Ma-tuoan-lin (Williams, 24) states that in May—June there was a comet near π Leonis, and another in June—July in the E.; whilst De Mailla (iv. 162) speaks of a third within the circle of perpetual apparition in August—September. Hind thinks that these three may easily have been but one.—(*Companion to the Almanac*, 1859, p. 20.) Pingré points out that the New Moon fell nearly at the time of the equinox, a circumstance which may have produced an error of one month in the Chinese dates.

[147.] 278. In May—June a very large comet appeared in Gemini. It lasted till the end of the year, or for 8 months (?).—(Ma-tuoan-lin; Gaubil.)

[148.] 279. In April a comet was seen in the sidereal division of δ, ε Hydræ; in May another (? the same) near π Leonis. In July—August it was within the circle of perpetual apparition.—(Ma-tuoan-lin; Williams, 25.)

[149.] 281 (i). In September a comet appeared in the sidereal division of κ, υ, λ Hydræ.—(Ma-tuoan-lin; Williams, 25.)

[150.] 281 (ii). In December a comet appeared near γ Leonis.—(Ma-tuoan-lin; Williams, 25.) This might be the same as the preceding, and Hind appears to favour this view of the matter.

[151.] 283. On April 22 a comet was seen in the S.W.—(Ma-tuoan-lin; Williams, 25.)

[152.] 287. In September a comet appeared in the sidereal division of φ Sagittarii for 10 days.) Its tail was 10 tchang (100 cubits ?) long.—(Ma-tuoan-lin; Williams, 25.)

[153.] 301 (i). In January a comet emerged to the W. of β Capricorni, with a tail pointing towards the W.—(Ma-tuoan-lin; Williams, 26.)

[154.] 301 (ii). In April—May a comet was seen near either ω Capricorni or 110 Herculis.—(Ma-tuoan-lin; Pingré.) Near H Herculis.—(Williams, 26.)

[155.] 302. In May—June a comet was visible in the morning.—(Ma-tuoan-lin; Williams, 26.)

[156.] 303. In April a comet was seen in the Eastern heavens, pointing towards ι, κ, λ, μ Ursæ Majoris.—(Ma-tuoan-lin; Williams, 27.)

[157.] 305 (i). In September—October a comet was seen in the sidereal division of the Pleiades.—(Ma-tuoan-lin; Williams, 27.) Under the same date De Mailla places a comet near the Pole.—(*Hist Gén.*, iv. 248.) This is probably the comet of Ma-tuoan-lin.

[158.] 305 (ii). On Nov. 22 a comet was seen in the square of Ursa Major, near γ of that constellation.—(Ma-tuoan-lin; Williams, 27.) Hind identifies this with the preceding, but not so Pingré.

[159.] 329. In August—September a comet appeared in the N.W. It entered the sidereal division of φ, δ Sagittarii, and was visible for 3 weeks.—(Ma-tuoan-lin; Williams, 27.)

[160.] **336.** On Feb. 16 in the evening a comet was seen in the W. in the sidereal division of β Andromedæ.—(De Mailla, iv. 349; Williams, 27.) In Europe a comet of extraordinary magnitude was seen for several days a year or more before the death of Constantine, which happened on May 22, 337.—(Eutropius, *Historia Romana*, x. 8.) Pingré and Hind agree in considering these 2 comets as one, in which case possibly it was visible for 2 or 3 months.

[161.] **340.** On March 5 or 25 a comet was seen in the vicinity of β Leonis.—(Ma-tuoan-lin; De Mailla, iv. 363; Williams, 28.)

[162.] **343.** On Dec. 8 a comet was seen; its R.A. exceeded that of κ Virginis by 7°.—(Gaubil.) Williams (p. 28) simply says that it was in the sidereal division of κ Virginis, and was 7 cubits long.

[163.] **349.** On November 23 a comet, with a tail 10 cubits long, and extending Westwards, was discovered in the sidereal division of κ Virginis. On Feb. 13, 350, it was still visible, and in the same sidereal division.—(Gaubil; Ma-tuoan-lin; Williams, 28.)

[164.] **358.** On July 1 or 12 a comet was seen in the sidereal division of Musca, near γ, η Persei.—(Williams, 28.)

[165.] **363.** In August—September a comet appeared in the sidereal divisions of α and κ Virginis; it subsequently passed to near α Herculis and α Ophiuci.—(De Mailla, iv. 413; Williams, 28.) During the reign of Jovian, or towards the end of the year, comets are said to have been visible in the daytime.—(Ammianus Marcellinus, *Rerum Gestarum*, xxv.)

[166.] **373** (i). On March 9 a comet appeared. It traversed the following sidereal divisions, *i. e.* its R.A. successively coincided with the following stars:—ϵ Aquarii, β Aquarii, α Libræ (April 7), α Virginis, κ Virginis, γ Corvi, α Crateris, and υ Hydræ.—(Ma-tuoan-lin; Williams, 29.) It is not impossible however that the comet traversed the above *constellations*, in which case the inclination of its orbit must have been very small.

[167.] **373** (ii). On Oct. 24 a comet appeared near α Herculis and α Ophiuchi.—(Ma-tuoan-lin.) Hind thinks that this was probably *Halley's comet*, which may have arrived at perihelion during the first week of November.—(*Companion to the Almanac*, 1859, p. 23.) Williams (p. 29) identifies this comet with the preceding, which is not a probable supposition. For Oct. 24 he gives Sept. 25.

[168.] **374.** In January—February a comet was visible in the sidereal division of μ^2 Scorpii and γ Sagittarii.—(De Mailla, iv. 437; Ma-tuoan-lin.) This position would also apply to Halley's comet at this epoch, so that it is uncertain whether this comet or the preceding one was that body.—(Hind.) Hind appears to give the preference to the latter. Compare his memoir in *Month. Not.*, vol. x. p. 57. Jan. 1850. Williams (p. 29) identifies this comet with 373 (i).

[169.] **375.** A few days before the death of Valentinian, which occurred on Nov. 17, comets were observed.—(Ammianus Marcellinus, *Rerum Gestarum*, xxx.)

[170.] **389.** In August (probably) a splendid comet appeared. It rose in the N., at the hour of cock-crowing. Resembling the morning star, it burned rather than shone, and ceased to exist in 4 weeks.—(Marcellinus, *Chronicon.*) It appeared in the zodiacal region, but moving apparently on the left of the spectators, and rising and setting with the morning star, it gradually advanced to Ursa Major and Minor. It lasted for about 6 weeks, and vanished near the centre of the former constellation.—(Philostorgius, *Epitome Historiæ Ecclesiasticæ*, x. 9; Nicephoras, *Historia Ecclesiastica*, xii. 37.)

[171.] **390.** On Aug. 22 a comet was seen near α and β Geminorum. Passing the vicinity of β Leonis, ι, κ, λ, θ, and ϕ Ursæ Majoris, it entered the "square" of that constellation; on Sept. 17 it arrived within the circle of perpetual apparition: its tail was 100 cubits long.—(Ma-tuoan-lin; Williams, 29.) It lasted 4 weeks.—(Marcellinus, *Chronicon.*) It is certain that 2 large comets appeared in 2 successive years, and, what is equally remarkable, that they both followed nearly the same path from the zodiac to the Pole; the first, seen, or at least recorded, only in Europe; the latter seen both in Europe and China. Marcellinus distinctly records *two* comets. One or other of them is probably the "new star" recorded by Cuspianinus.

[172.] **392.** A comet appeared.—(Couplet.)

[173.] **395.** A great comet appeared in August, which moved from ϵ Sagittarii towards β Aquarii and α Equulei.—(De Mailla, iv. 496.)

[174.] **400.** On March 19 a comet, 30° long, appeared in the sidereal division of θ Andromedæ. It rose to ϵ, υ, ξ Cassiopeiæ, and stopped to the W. of the circle of perpetual apparition; it entered the square of Ursa Major, and arrived near ν, ξ, λ, μ, ι, κ. In the next moon (commencing April 11) it passed by β Leonis to β and η Virginis.—(Ma-tuoan-lin; Williams, 30.) Gaubil adds that the comet passed very near χ Ursæ Majoris. The most terrible comet on record. Its form was that of a sword.—(Socrates Scholasticus, *Historia Ecclesiastica*, vi. 6.)

[175.] **401.** On January 2 a comet appeared in Corona Borealis and near α Herculis and α, β, ϵ, &c. Cygni.—(De Mailla, iv. 519; Williams, 30.)

[176.] **402-3.** In November—December an extraordinary star appeared to the W. of the region lying around β Leonis; two moons later it was nearer that star.—(Biot*; Williams, 31.) "It first appeared in the E. towards that part of the heavens where Cepheus and Cassiopeia shine. Passing then a little beyond the Great Bear, it overpowered by [the brilliancy of] its wandering hair the beauty of the stars of that constellation, till at length it languished, and finally dissipated itself in a very feeble flame."—(Claudianus, *De Bello Getico*, xxvi. 28 *et seq.*)

[177 and 178.] **415** *or* **416**; (i and ii). On June 24 two comets were observed near α Herculis and α Ophiuchi; passing by the former star they were seen in the N. of the sidereal divisions π and σ Scorpii.—(Ma-tuoan-lin; Williams, 31 and 35.) Probably this route applies to only one of the comets. From another Chinese Chronicle it appears that on June 18, 416, two comets were visible. It is most unlikely that in 2 consecutive years in the same moon and on the same day of the moon [Chinese reckoning] 2 pairs of comets should have appeared, so (as Pingré suggests) probably there was only 1 pair, one or the other of the 2 historians having accelerated or retarded their appearance by one year.

[179.] **418** (i). On June 24 a comet was discovered in the middle of the square of Ursa Major.—(Ma-tuoan-lin.) "Cette comète diffère necessairement de la suivante." —(Pingré, i. 599.)

[180.] **418** (ii). "On July 19, towards the 8th hour of the day, the Sun was so eclipsed that even the stars were visible. But at the same time that the Sun was thus hid, a light, in the form of a cone, was seen in the sky; some ignorant people called it a comet, but in this light we saw nothing that announced a comet, for it was not terminated by a tail: it resembled the flame of a torch, subsisting by itself without any star for its base. Its movement too was very different from that of a comet. It was first seen to the E. of the equinoxes; after that, having passed through the last star in the Bear's tail [probably η Ursæ Majoris], it continued slowly its journey towards the W. Having thus traversed the heavens, it at length disappeared, having lasted more than 4 months. It first appeared about the middle of the summer, and remained visible until nearly the end of autumn."—(Philostorgius, *Epitome Historiæ Ecclesiasticæ*, xii. 8.) This description has been taken by some to apply to the Zodiacal Light. (Boillot, *Traité d'Astronomie*, p. 257.)
In China this comet was seen on Sept. 15 in Leo: it rose above δ or σ Leonis, and passed through the square of Ursa Major, the circle of perpetual apparition, and near ι and κ (or λ and μ) Ursæ Majoris. Its tail, short at first, increased to 100 cubits or more.—(Ma-tuoan-lin; Williams, 31.) It was first seen near δ Cygni, and was visible for 11 weeks.—(De Mailla, iv. 590.) Couplet states that it appeared in November—December. If for *appeared* we could read *disappeared*, Couplet's account would harmonise with those of the other observers.

[181.] **419.** On Feb. 17 a comet appeared in the W. of the region lyiug around β Leonis.—(Ma-tuoan-lin; Williams, 31.)

[182.] **420** *or* **421.** In May a comet was seen.—(Couplet.) In Europe a wonderful sign appeared in 421.—(Prosperus Tyronus, *Chronicon.*) Was this "sign" the comet of the Chinese?

[183.] **422** (i). In March a star with a long white ray appeared for 10 nights about the time of the cock-crowing.—(*Chronicon Paschale.* Parisiis, 1688.) On March 16 it was in the sidereal divisions of α and β Aquarii.—(Gaubil.) Ma-tuoan-lin dates its appearance for March 21.—(Williams, 32.)

[184.] **422** (ii). On Dec. 17 a comet was seen near α and β Pegasi.—(Ma-tuoan-lin; Williams, 32.)

[185.] **423** (i). On Feb. 13 a comet was seen in the eastern part of the sidereal division of γ Pegasi.—(Ma-tuoan-lin; Williams, 32.) A comet was frequently seen before the death of the emperor Honorius.—(Marcellinus, *Chronicon.*) This event happened in August.

[186.] **423** (ii). On Oct. 15 a comet was seen in the sidereal division of α and β Libræ.—(Ma-tuoan-lin; Williams, 32.) Hind gives the date as Dec. 14.

[187.] **432**. A comet was seen near α and γ Leonis; passing in the vicinity of β Leonis, it disappeared near α Boötis.—(Ma-tuoan-lin.) No moon given.

[188.] **436**. On June 21 a comet was seen near π Scorpii.—(Gaubil.)

[189.] **442**. On Nov. 1 a comet without a tail was seen in the square of Ursa Major. It soon threw out a tail, and passing θ, v Ursæ Majoris, through Auriga, ρ and π Tauri, came to π Ceti and γ, δ, μ Eridani. It disappeared in winter.—(Ma-tuoan-lin; Biot*; Williams, 32.) It appeared in December, and remained visible for several months.—Marcellinus, *Chronicon;* Idatius, *Chronicon.*)

[190.] **449**. A comet appeared on Nov. 11 in the vicinity of β Leonis.—(Ma-tuoan-lin; Williams, 33.)

[191.] **467**. A comet resembling a trumpet was seen for periods of from 10 to 40 days in the evening sky.—(*Chronicon Paschale;* Theophanes, *Chronographia,* p. 99, Parisiis, 1655.)

[192.] **499**. A comet appeared previous to the second invasion of Illyria by the Bulgarians.—(Zonaras, *Annales,* ii. 56. Parisiis, 1686.)

[193.] **501**. On Feb. 13 a tailed star appeared in the horizon. On March 2 a grand comet was visible.—(Ma-tuoan-lin. Hind, *Companion to the Almanac,* 1860, p. 78.) For March 2, Williams (p. 33) reads April 14. Probably these notes belong to one and the same object.

[194.] **504**. A great and brilliant star, with a long ray, appeared about the time of the death of Ambrosius Aurelius.—(Galfredus, *De Origine et gestis Regum Britanniæ,* viii. 4. Heidelbergæ, 1587.) It is just possible that this description may refer to the preceding comet. Hind seems to be of this opinion.

[195.] **507**. On Aug. 15 a comet was seen in the N. E.—(Gaubil.)

[196.] **519**. A "fearful star," with a tail turned towards the W., was seen this year, possibly between October and December.—(Theophanes, *Chronographia,* p. 142; Malala, *Historia Chronica,* xvii. Venetiis, 1733.)

[197.] **520**. On Oct. 7 a comet, bright like fire, was seen in the E. On Nov. 30 it was observed in the morning.—(Gaubil.)

[198.] **524**. A star was seen for 26 days and nights "above the gate of the palace."—(Cedrenus, *Compendium Historiarum,* p. 365. Parisiis, 1647.)

[199.] **530** *or* **531**. A great comet was observed in Europe and China, but accounts differ as to the year, though probably it was 531. "It was a very large and fearful comet," and was seen in the W. for 3 weeks. Its rays extended to the zenith.—(Theophanes, *Chronographia,* p. 154; Malala, *Historia Chronica,* xviii.) It was observed [? passed] in October from α Boötis to λ, μ Ursæ Majoris.—(De Mailla, v. 299.) Hind thinks that this was *Halley's comet.* If it arrived in perihelion at the beginning of November it would have occupied the positions given by the historians, and, in any case, it must have been near perihelion at this time. It is not impossible that there was a comet in each of the above years, a theory which might perhaps remove some of the discrepancies which exist on the assumption that there was only one.

[200.] 533. On March 1 a great star appeared.—(Ma tuoan-lin). There are no further particulars, so it is uncertain whether this was a comet or a temporary star (Hind). Williams (p. 33) gives, but with reserve, the date as January 6, 532. He calls the object, however, a tailed star, in which case no doubt it was really a comet.

[201.] 534. A comet appeared in Leo and Virgo; passing ν, ξ Ursæ Majoris, it moved to the square of Pegasus.—(Gaubil.)

[202.] 556. In November a comet, in the form of a lance, extended from E. to W., or from N. to W.—(Malala, *Historia Chronica*, xviii.) Some writers date this for 555.

[203.] 560. On Oct. 4 a comet, with a tail 4 cubits long, pointing towards the S. W., was seen.—(Williams, 34; Gaubil.)

[204.] 563. A comet, like unto a sword, was seen for a whole year [? month].—(Gregorius Turonensis, *Historia Francorum*, iv.)

[205.] 565 (i). On April 21 a comet appeared.—(Ma-tuoan-lin.) Williams (p. 35) thinks that there is some uncertainty about the year.

[206.] 568 (i). On July 20 a very brilliant comet was seen in the sidereal division of μ Geminorum. It moved towards the E., and stopped 8 "feet" [or degrees?] N. of θ, η Cancri on Aug. 18, and then disappeared.—(Ma-tuoan-lin; Biot; Williams, 36).

[207.] 575. On April 27 a comet was seen near Arcturus (α Boötis).—(Ma-tuoan-lin; Williams, 34.)

[208.] 581. On Jan. 20 a comet appeared in the S. W.—(Ma-tuoan-lin.) Williams (p. 35) dates this comet for Jan. 26, 580.

[209.] 582. In the month of January many prodigies were seen. A comet appeared, situate, as it were, in a sort of opening; it shone in the midst of the darkness, sparkled and spread out its tail. From the comet a ray of surprising magnitude emanated, which appeared like the smoke of a conflagration as viewed at a distance. The comet was visible in the W. from the first hour of the night.—(Idatius, *Chronicon*, vi. 14.)

[210.] 584. A comet, like a column of fire suspended in the air, was observed, and a great star appeared above it.—(*Chronicon Turonense.*)

[211.] 588. On Nov. 22 a comet appeared near β Capricorni.—(Ma-tuoan-lin; Williams, 38.)

[212.] 591. A comet appeared for 1 month.—(Bonfinius, *Rerum Hungaricum*, I. viii., Hanoviæ, 1606.)

[213.] 595. On Jan. 9 a comet was visible in the sidereal division of β Aquarii. It moved through the sidereal division of α Aquarii and ϵ Pegasi, towards those of β Andromedæ and β Arietis.—(Gaubil; Ma-tuoan-lin; Simocatta, *Historia*, vii., Parisiis, 1647.) Williams (p. 38) dates this comet for Nov. 10, 594.

[214.] 602. A comet, like unto a sword, was seen in this year.—(Theophanes, *Chronographia*, p. 240.)

[215.] About 605 (i). In April and May a comet was seen.—(Paulus Diaconus, *De Gestis Longobardorum*, iv. 33.)

[216.] About 605 (ii). In November and December a comet was seen.—(Paulus Diaconus, iv. 34.)

[217.] 607 (i). On March 13 a comet was seen in the sidereal division of μ Geminorum, and near v, ϕ Ursæ Majoris; it passed by κ, τ, θ &c. Persei, α, β, θ, χ Aurigæ, α, β Geminorum, the *vicinity* of β Leonis and α Herculis, and stopped after 14 weeks. (Ma-tuoan-lin; Williams, 38.) Probably for Ti-tso (α Herculis) we should read, as Hind suggests, Ou-ti-tso (β Leonis); and if we suppose the "v and ϕ Ursæ Majoris" to allude to the place to which the tail extended, this otherwise inconceivable route will appear more reasonable.

On April 4 a tailed star appeared in the W. horizon. It traversed the sidereal divisions of β Andromedæ, α and β Arietis, and α and κ Virginis, and then disappeared.—(Gaubil; Williams, 39.) The Chinese account refers this to another comet, but Hind thinks "it is more than probable that in the description of these so-called *first* and *second* comets of this year, there is some confusion as regards the order in which a single comet may have passed through these sidereal divisions and constellations; or observations of the direction of the tail may be mixed up (as occasionally happens) with the positions of the head."—(*Companion to the Almanac*, 1860, p. 85.)

[218.] **607** (ii). On Oct. 21 a comet appeared in "the Southern region;" it was seen in the sidereal divisions of α and κ Virginis and, passing in the vicinity of β Leonis, came to α Herculis: it entered most of the sidereal divisions, but not those of α, β, γ, δ Orionis or γ, ϵ, μ Geminorum; in the beginning of the year 608 it disappeared.—(Williams, 39; Ma-tuoan-lin; who declares this comet to be identical with that of the 4th of April.) For α Herculis, Pingré read β Leonis, as above, and thinks the "European comet or comets of 605 the same as the Chinese comet or comets of 607."—(*Comét.* i. 327.) It is very difficult to decide from the Chinese observations of comets in 607 how many comets really appeared in that year—whether there were 2 or 3, or even more than one.

[219.] **608**. A comet emerged this year from α, β Aurigæ, and passing ν, ϕ &c. Ursæ Majoris, came to β, δ, π, ρ Scorpii.—(Ma-tuoan-lin.) This is precisely the path which *Halley's comet* follows when its PP. occurs in October, and as that comet was due about this year, Hind thinks this was it.

[220.] **614**. A comet appeared for 1 month during the occupation of Jerusalem by Cosroës, king of Persia.—(Lubienitz, *Theatrum Cometicum*, Lugd. Bat. 1681.) Date *very uncertain.*

[221.] **615**. In July a comet was seen to the S. E. of h, ν, ϕ, θ Ursæ Majoris. It was from 50° to 60° long, and its extremity had an undulatory motion. It moved to the N. W. for some days, and when it had nearly reached the circle of perpetual apparition it retrograded, and then disappeared.—(Gaubil; Ma-tuoan-lin.) The dimensions assigned by the latter are 5 or 6 tsun ($\frac{5}{10}$ or $\frac{6}{10}$ of a cubit?).—Williams, 39.)

[222.] **616** (i). In July a comet, with a tail 3 or 4 cubits long, was seen near β Leonis; after some days it disappeared.—(Ma-tuoan-lin; Williams, p. 39). Hind assigns this and the next comet to the year 617.

[223.] **616** (ii). In October a comet appeared in the sidereal division of α, β Pegasi.—(Ma-tuoan-lin; Williams, 39.)

[224.] **622**. A comet is recorded by several modern cometographers.—(Lubienitz.)

[225.] **626**. In March an extremely brilliant star was seen in the W. after sunset.—(*Chronicon Paschale.*) On March 26 it was situated between the sidereal divisions of the Pleiades and Musca. On March 30 it was near ν, ϵ, ξ Persei.—(Gaubil; Williams, 40.)

[226.] **632**. In May or June, or a little later, a sign appeared for 4 weeks in the S. It was called a "beam," and extended from S. to N.—(Cedrenus, *Compendium Historiarum*, p. 425. Parisiis, 1647.)

[227.] **633**. A comet, in the form of a sword, was seen.—(J. A. Weber, *Discursus Curiosi*, &c. Salisburgi, 1673.)

[228.] **634**. On Sept. 22 a comet appeared in the sidereal divisions of β Aquarii and α Aquarii; it passed through the sign Aquarius, and on Oct. 3 was not visible.—(Gaubil; Williams, 40.)

[229.] **639**. On April 30 a comet was seen in the sidereal divisions of α Tauri and Pleiades.—(Ma-tuoan-lin; Williams, 40.) One Chinese authority makes the year 638.

[230.] **641**. On July 22 a comet was seen in the region near β Leonis; it approached Coma Berenicis, and on Aug. 26 it had disappeared.—(Ma-tuoan-lin.) De Mailla (vi. 93) dates this comet a month earlier, and Gaubil and Williams (p. 40) say it was in the β Leonis region on Aug. 1.

[231.] **660.** Some *modern* cometographers state that a comet was visible in Scorpio for 12 days.—(Lubienitz.)

[232.] **663.** On Sept. 27 a comet, 2 cubits long, was seen near o, π, ζ Boötis. On Sept. 29 it had disappeared.—(Ma-tuoan-lin.) For Sept. 27 and 29 Williams (p. 41) reads Sept. 29 and Oct. 1.

[233.] **667.** On May 24 a comet was seen in the N. E., near β, θ Aurigæ, and β Tauri.—(Gaubil.) On June 12 it had disappeared.—(Ma-tuoan-lin ; Williams, 41.)

[234.] **668.** In May or June a comet was seen for a few days in Auriga.—(De Mailla, vi. 145.) This is probably identical with the preceding with an error of one year in the date.

[235.] **673.** In the first year of Thierri of France a comet was observed.—(*Vita S. Leodegarii.*) Several historians record a fire or extraordinary iris. Pingré suggests that the whole may be reduced to an Aurora Borealis.

[236.] **674.** According to some modern writers a great comet appeared.—(Lubienitz.)

[237.] **676** (i). On Jan. 3 a comet, 5 cubits long, was discovered to the S. of the sidereal divisions of α and κ Virginis.—(Ma-tuoan-lin ; Williams, 41.)

[238.] **676** (ii). "In the month of August a comet showed itself in the E. for 3 months, from the time of cock-crowing until morning. Its rays penetrated the heavens; all nations beheld with admiration its rising: at length, returning upon itself, it disappeared."—(Anastasius, *Historia Ecclesiastica*, Parisiis, 1649; Paulus, Diaconus, *De Gestis Longobardorum*, v. 31.) On Sept. 4 a comet appeared in the sidereal division of μ Geminorum; it pointed towards α and β Geminorum; it moved towards the N.E. Its tail, at first 3 cubits long, afterwards increased to 30 cubits. It [the *comet*—Pingré; or the *tail*—Hind] reached to λ, μ and θ, ν, ϕ Ursæ Majoris. On Nov. 1 the comet had disappeared.—(Ma-tuoan-lin; Gaubil.) For Sept. 4 and Nov. 1 in this account, Williams (p. 41) reads July 7 and Sept. 3.

[239.] **681.** On Oct. 17 a comet, 50° long, was near α Herculis; gradually diminishing in size, it moved towards α, β, γ Aquilæ, and on Nov. 3 it had disappeared. —(Gaubil; Ma-tuoan-lin; Williams, 42.)

[240.] **683.** On April 20 a comet was seen to the N. of α, β, θ, &c. Aurigæ, β Tauri. On May 15 it had disappeared.—(Ma-tuoan-lin; Williams, 42.)

[241.] **684** (i). On Sept. 6 a comet, 10° long, was seen in the evening towards the W. On Oct. 9 it had disappeared.—(Gaubil.) Hind remarks that this single account will tolerably well describe the position which *Halley's comet* must have been in at its return to perihelion in the year 684, so doubtless this was that celebrated body. —(*Companion to the Almanac*, 1860, p. 88.) For Sept. 6 and Oct. 9 Williams (p. 42) reads July 8 and Aug. 10.

[242.] **684** (ii.) On Nov. 11 a star, like a half moon, was seen in the W. country. —(Ma-tuoan-lin.) Hind says "in the *north*"—apparently a misprint. For Nov. 11 Pingré and Biot read Oct. 11, and Williams (p. 42) Sept. 12. It seems doubtful whether a comet is referred to.

[243.] **706.** In the 3rd year of Ethelhard King of Wessex "Two comets appeared ...one in the evening, the other in the morning; one in the West, the other in the East. They carried their fiery face towards the North, and appeared during the month of January for almost a fortnight."—(Bartholomæi de Cotton, *Historia Angliæ.*) This is no doubt one comet with a considerable North Declination.

[244.] **707.** On Nov. 16 a comet appeared in the W.; on Dec. 17 it had ceased to be visible.—(Ma-tuoan-lin; Williams, 43.)

[245.] **708** (i). On March 30 a comet appeared between the sidereal divisions of Musca and the Pleiades.—(Ma-tuoan-lin ; Williams, 43.)

[246.] **708** (ii). On Sept. 21 a comet appeared within the circle of perpetual apparition.—(Ma-tuoan-lin ; Williams, 43.)

[247.] **710** *or* **711.** In the 92nd year of the Hegira a comet, endued with a sensible motion, appeared for 11 days.—(Haly, *Liber Ptolemæi Comment.* Venetiis, 1484.) The year 92 of the Hegira commenced on Oct. 29, 710, and ended on Oct. 18, 711.

[248.] **712.** In August—September a comet emerged from the W., and passed near β Leonis, &c. and thence to Arcturus.—(De Mailla, vi. 199.) Williams (p. 43) sees a difficulty in assigning any more exact date than "between 710 and 713."

[249.] **716.** A comet of terrible aspect, with its tail directed towards the Pole, is said to have been seen this year, but we have only a modern authority for the statement.—(Sabellicus, *Opera Omnia*, Ennead. VIII. lib. vii. Basileæ, 1560.)

[250.] **729.** Several writers speak of 2 comets visible for 14 days in the month of January, the one after sunset and the other before sunrise.—(Bede, *Historia Ecclesiastica*, v.; Monachus Herveldensis, *Chronicon Historiæ Germaniæ.*) It is easy to see that a single comet with a R.A. not greatly differing from that of the Sun, but with a high North declination, would be seen after sunset and before sunrise, and thus satisfy the statement of the Chroniclers. Donati's great comet of 1858 was so visible for several weeks in the month of September of that year.

[251.] **730.** On Aug. 29 a comet was seen in Auriga: on Sept. 7 it was in the sidereal divisions of α, γ &c. Tauri and the Pleiades.—(Gaubil.) Ma-tuoan-lin implies that the comet of Sept. 7 was not the same as that of Aug. 29. Williams's dates are June 30 and July 9 (p. 43).

[252.] **738.** On April 1 a comet was seen within the circle of perpetual apparition. It traversed the square of Ursa Major, and was observed for 10 days or more, when clouds interfered.—(Ma-tuoan-lin.) Williams (p. 44) dates this comet for 739.

[253.] **744.** A great comet was seen in Syria.—(Theophanes, p. 353.)

[254.] **749.** "In his (Cuthrede's) time there appeared 2 blasing stars casting as it were burning brands towards the North.—(Stowe, *Chronicles.*)

[255.] **762.** A comet was seen in the E. like unto a beam.—(Theophanes, p. 363.)

[256.] **767.** On Jan. 12 a comet 1 cubit long was seen near α, β, γ, δ Delphini. It passed over ϵ, ι Delphini and was visible for 3 weeks.—(Ma-tuoan-lin; Williams, p. 44.) For Jan. 12 Hind reads Jan. 22.

[257.] **773.** On Jan. 17 a tailed star was seen in the sidereal division of δ Orionis. —(Ma-tuoan-lin; Williams, 45.)

[258.] **813.** "On Aug. 4 a comet was seen which resembled 2 Moons joined together; they separated, and having taken different forms, at length appeared like a man without a head."—(Theophanes, p. 423.) In spite of the strangeness of this description, Pingré considers it to be really that of a comet, and thinks it possible to find an explanation in the comet's peculiar position with regard to the Sun and the Earth.—(*Comét.* i. 338.)

[259.] **815.** In April—May a great comet appeared near β Leonis.—(Ma-tuoan-lin; Williams, 45.)

[260.] **817.** On Feb. 5, at the second hour of the night, a monstrous comet was seen in Sagittarius.—(*Vita Ludovici Pii* in Bouquet's Collection, vi.) On Feb. 17 a comet was seen in the sidereal division of α, γ Tauri.—(Ma-tuoan-lin; Williams, 45.)

[261.] **821** (i). On Feb. 27 a comet was seen in the sidereal division of α Crateris. On March 7 it was near σ Leonis.—(Ma-tuoan-lin; Williams, 46.)

[262.] **821** (ii). In July a comet, with a tail 10 cubits long, was seen in the sidereal division of the Pleiades. After 10 days it disappeared.—(Ma-tuoan-lin; Williams, 46.)

[263.] **828.** On Sept. 3 a comet, with a tail 2 cubits long, was seen near τ, υ, η Boötis.—(Ma-tuoan-lin.) A comet in Libra.—(Georgius Fabricius, *Rerum Germaniæ ... Memorabilium.* Lipsiæ, 1609.) Pingré, not then acquainted with Ma-tuoan-lin, threw doubts on the value of the record for Sept. 3. Williams (p. 46) reads July 5.

[264.] 834. On Oct. 9 a comet, with a tail 10° long, was seen near β Leonis. It went Northwards beyond Coma Berenicis. On Sept. 7 it had disappeared.—(Ma-tuoan-lin; Williams, 46.

[265.] 837 (ii). On Sept. 10 a comet was seen in the sidereal divisions of β and *d* Aquarii.—(Ma-tuoan-lin; Boethius, *Scotorum Historia*, x; Williams, 48.)

[266.] 838 (i). On Nov. 11 a comet was seen in the sidereal divisions of β Corvi and θ Cancri. It was 20 cubits long, and the tail gradually pointed to the W.—(Ma-tuoan-lin; Williams, 48.)

[267.] 838 (ii). On Nov. 21 a comet was seen in the E. country, in the sidereal divisions μ^2 Scorpii and γ Sagittarii. It extended in the heavens E. and W. On Dec. 28 it had disappeared.—(Ma-tuoan-lin.) For Dec. 28, Williams (p. 49) reads Dec. 8. Possibly this and the preceding account both relate to the same object.

[268.] 839 (i). On Jan. 1 a comet was seen in Aries.—(*Annales Francorum Fuldenses*, in Bouquet's Collection, vols. vii. and viii.) On Feb. 7 a comet was seen near δ, τ, χ, ψ Aquarii.—(Ma-tuoan-lin; Williams, 49.) Pingré thinks that the latter could not have been the European comet of Jan. 1.—(*Comét.* i. 614.)

[269.] 839 (ii). On March 12 a comet was seen to the N. W. of ν, ε, ξ, ζ Persei. On April 14 it had disappeared.—(Ma-tuoan-lin; Williams, 49.)

[270.] 840 (i). On March 20 a comet was seen between the sidereal divisions of α and γ Pegasi. After 3 weeks it disappeared.—(Ma-tuoan-lin; Williams, 49.)

[271.] 840 (ii). On Dec. 3 a comet was seen in the E. country.—(Ma-tuoan-lin; Williams, 49.)

[272.] 841 (i). Before the battle of Fontenay, that is, before June 25, a comet was seen in Sagittarius.—(*Annales Francorum Fuldenses.*) In July—August a comet was seen near δ, τ, χ, ψ Aquarii and between γ Pegasi and the E. of the sidereal division of γ Pegasi.—(Ma-tuoan-lin; Williams, 49.)

[273.] 841 (ii). On Dec. 22 a comet was seen near α Piscis Australis; it passed through the wing of Pegasus into the circle of perpetual apparition. On Feb. 9, 842, it had disappeared.—(Gaubil; Williams, 50.) It was seen in the W. from Jan. 7 till Feb. 13.—(*Chronicon Turonense.*)

[274.] 852. In March—April a comet was seen in the sidereal divisions of λ and δ Orionis.—(Ma-tuoan-lin; Williams, 50.) Williams dates this comet for 851.

[275.] 855. A comet was seen in France for 3 weeks.—(*Chronicon S. Maxentii*; in Bouquet's Collection, vols. vii. and ix.) Perhaps in the month of August.

[276.] 857. On Sept. 22 a comet, with a tail 3 cubits long, was seen in the sidereal division of π Scorpii.—(Ma-tuoan-lin.) Williams (p. 50) dates this comet for Sept. 27, 856.

[277.] 858. At the time of the death of Pope Benedict III a comet appeared in the E.; its tail was turned towards the W.—(Ptolemæus Lucensis, *Historia Ecclesiastica*, xvi. 9, in Muratori's Collection, vol. xi.) Benedict died on April 8.

[278.] 864. On May 1 a comet was seen.—(*Chronicon Floriacense.*) On June 21 a comet was seen in the N. E. through an opening in the clouds for 15 minutes. It was in the sidereal division of β Arietis, and had a tail 3 cubits long.—(Ma-tuoan-lin; Williams, 30.)

[279.] 866. Comets were seen before the death of Bardas.—(Constantinus Porphyrogenitus, *Incerti Continuatoris*, iv. p. 126.) Bardas was killed on April 21.

[280.] 868. About Jan. 29 a comet was seen for 17 days. It was under the tail of the Little Bear and advanced to Triangulum.—(*Annales Francorum Fuldenses.*) It was seen in China in the sidereal divisions of β Arietis and α Muscæ.—(Ma-tuoan-lin; Williams, 51.)—This comet is probably identical with Nos. 23 and 241 of the other catalogue, all three objects being apparitions of what is now known as the "November meteor comet." (See Hind, *Month. Not.* xxxiii. 48. Nov. 1872.)

[281.] **869.** A comet announced the death of Lotharius the Younger.—(Pontanus, *Historia Gelrica*, v. Hardervici-Gelrorum, 1639.) Lotharius died on Aug. 8. In September—October a comet was observed near χ, κ, θ, τ, β, ρ Persei. It went to the N. E.—(Ma-tuoan-lin; Williams, 51.)

[282.] **873.** A comet was seen in France for 25 days.—(*Chronicon Andegavense*, in Bouquet's Collection, vol. vii.)

[283.] **875.** The death of the emperor Louis II. was announced by a burning star, like a torch, which showed itself on June 7 in the N. It was seen also from June 6 in the N. E. at the first hour of the night. It was more brilliant than comets usually are, and had a fine tail. This bright comet, with its long tail, was seen morning and evening during the whole of June. (*Breve Chronicon Andreæ*, in Bouquet's Collection, vol. vii.) After harmonising some discrepancies of dates, Pingré says the comet would have appeared on June 3 in Aries; having but little latitude, it would consequently have risen a little after midnight, and would have been seen the same night. The following days, as its longitude diminished and its N. latitude increased, it would have been seen by June 6 or June 7, in the evening, towards the N. E.—(*Comét.* i. 349.)

[284.] **877.** "In the second year of the entrance of Charles the Bald into Italy a comet was seen in the month of March in the W., and in the sign Libra. It lasted for 15 days, but was less bright than the preceding one [that of 875]. In the same year the emperor Charles died."—(*Chronicon Novaliciense*, in Muratori's Collection, vol. ii.) Being in Libra, it was in opposition to the Sun, and therefore visible all night, in the evening in the E. and in the morning in the W.—(Pingré, *Comét.*, i. 350.) Ma-tuoan-lin says that it appeared in the 5th moon, or in June—July. (Williams, 51.)

[285.] **882.** On Jan. 18, at the 1st hour of the night, a comet, with a prodigiously long tail, was seen.—(*Annales Francorum Fuldenses.*)

[286.] **885.** A comet was seen between λ, μ Persei and κ Geminorum.—(Ma-tuoan-lin; Williams, 51.)

[287.] **886.** On June 13 a comet was seen in the sidereal divisions of μ^2 Scorpii and γ Sagittarii. It passed α, β, γ Ursæ Majoris, near to θ, π, ζ or η, τ, υ Boötis.—(Ma-tuoan-lin; Williams, 51.)

[288.] **890.** About May 23. "Ging ein Comet mit haufenförmiger Hülle auf; Später wurde die Hulle zum Schweife." (Tabarî III. 2119, 10: *Ast. Nach.*, No. 2811. vol. cxviii. Nov. 9, 1887.)

[289.] **891.** On May 12 a comet, with a tail 100 cubits long, appeared near the feet of Ursa Major; it went towards the E. It passed by the vicinity of β Leonis to α Boötis and Serpens, etc. On July 5 it had disappeared.—(Ma tuoan-lin; Williams, 51; J. Asserius, *Annales.*)

[290.] **892** (i). A comet appeared this year in the tail of Scorpio. It lasted 12 weeks, and was followed by an extreme drought in April and May.—(*Chronicon Andegavense.*)

[291.] **892** (ii). In June a comet, with a tail 2° long, appeared.—(Ma-tuoan-lin.)

[292.] **892** (iii). In November—December a comet appeared in the sidereal divisions of ϕ Sagittarii and β Capricorni.—(Ma-tuoan-lin; Williams, 52.)

[293.] **892** (iv). On Dec. 28 a comet came from the S. W. On Dec. 31, the sky being cloudy, it was not seen.—(Ma-tuoan-lin.)

Possibly i. and ii. are identical, and also iii. and iv.; and in that case there would have been only 2 comets this year.

[294.] **893.** After several months of very bad weather the clouds went away, and on May 6 a comet was seen near ι and κ Ursæ Majoris, with a tail 100° long. It went towards the E., entered the region lying around β Leonis, and traversed Boötes, near Arcturus passing into the region around α Herculis. It was visible for 6 weeks, and its length gradually increased to 200° (?). The clouds then hid it.—(Ma-tuoan-lin.) The length is incredible, though Gaubil gives the same. Gaubil's date is 895, but

Pingré is sure that 893 was the year. Williams (p. 52) pronounces in favour of 893, but misquotes Pingré in doing so.

[295.] **894.** In February—March a comet was seen. It had the same R. A. as Gemini or Cancer.—(Ma-tuoan-lin; Williams, 52.)

[296.] **896.*** In this year there appeared 3 extraordinary stars, one large and two smaller ones. They were between the divisions of β and α Aquarii. They travelled together for 3 days. The little ones disappeared first, and then the large one.—(Biot.)

[297.] **900.** About February an extraordinary star appeared near e Herculis, ι Ophiuchi, W. of α Herculis.—(Biot.*) A comet appeared.—(Lubienitz.)

[298.] **902.** About February an extraordinary star was seen below some stars in Camelopardus. After a little while it passed to χ Draconis. On March 2 a shooting star touched it. On March 4 it returned to Camelopardus.—(Biot.*) A comet appeared.—(Calvisius, *Opus Chronologicum.* Francofurti-ad-Oderam, 1620.)

[299.) **904.** At about the time of the birth of the Emperor Constantine Porphyrogenitus a brilliant comet showed its rays in the E. It lasted 40 days and 40 nights. —(Leo Grammaticus, *Chronographia*, p. 483.) Constantine was baptized on the festival of the Epiphany, or on Jan. 6, 905; so the comet may be dated for November and December 904.

[300.] **905.** On May 22 a comet was seen near α, β Geminorum. It traversed Ursa Major from θ, υ, ϕ, τ past λ, μ, towards ν, ξ. The tail was 30 cubits long. On June 12 the comet stretched from α and γ Leonis towards Serpens: on June 13 clouds obscured the sky; and on June 18 the comet had disappeared.—(Ma-tuoan-lin; Williams, 52.) From the European account in the *Chronicon Floriacense* it would rather seem that it was the *head* of the comet which was in Ursa Major, and that the tail reached to the zodiacal region; but the description is altogether very vague. In all such cases the Chinese accounts are generally preferable.

[301.] **911.** About June an extraordinary star appeared near α Herculis.—(Biot.*) A comet appeared.—(Ordericus Vitalis, *Historia Ecclesiastica*, vii.) Pingré, perhaps it may *now* be said without reason, refers this account of Ordericus to the next comet.

[302.] **912.** A comet appeared for 15 days in the W., like unto a sword.—(Leo Grammaticus, *Chronographia*, p. 487. Parisiis, 1655.) It lasted for 14 days in the N. W. in March.—(Hugo, Monachus Floriacensis, *Chronicon*, in Bouquet's Collection, vol. viii.) On May 13 a comet was seen in the sidereal division of ν Hydræ. On May 15 it was near χ Leonis.—(Ma-tuoan-lin; Williams, 53.) Probably *Halley's comet*, the PP. occurring early in April.—(Hind, *Month. Not.* R.A.S., x. 55. Jan. 1850.)

[303.] **912** *or* **913.** A comet was seen in Egypt in the year 300 of the Hegira.—(Haly, *Liber Ptolemæi Comment.*) That year commenced on Aug. 18, 912, and ended on Aug. 6, 913.

[304.] **916.** In the 15th year of Edward, son of Alfred, a comet appeared.—(Bartholomæi de Cotton, *Historia Angliæ.*)

[305.] **923.** In November—December a comet was seen near θ, γ, δ Cancri.—(De Mailla, vii. 210.) Another authority ante-dates this comet 1 month.

[306.] **928.** On Dec. 13 a comet was seen in the S. W. Its R. A. was 5° greater than that of β Capricorni. Its tail was 10° long, and pointed to the S. E. After 3 evenings it ceased to be visible.—(Ma-tuoan-lin.) For Dec. 13 Williams (p. 53) reads Oct. 14.

[307.] **936.** On Sept. 21 a comet appeared in the sidereal divisions of β and α Aquarii. It was 1° long, and passed near ξ Aquarii and λ, μ Capricorni.—(Ma-tuoan-lin.) For Sept. 21 Williams (p. 54) reads Oct. 28.

[308.] **939.** "There was seen in Italy, for 8 successive nights, a comet of surprising grandeur: it threw out rays of extraordinary length."—(Luitprandi Ticinensis, *Rerum . . . Gestarum*, V. i.) Possibly July was the month.

[309.] **941.** On Sept. 18 or Nov. 17 (it is not possible to say which, though the former day seems the more likely, from the European account) a comet appeared in the W. It swept Serpens and Hercules, and was 10 cubits long.—(Ma-tuoan-lin; Williams, 54.) It was seen in October for 3 weeks.—(*Chronicon S. Florentii*, in Bouquet's Collection, vols. vii. and ix.) Another Chinese account dates this comet for Aug. 7.—(Williams, 64.)

[310.] **942.** In October a comet appeared for 3 weeks in the W.: it had a long tail, and advanced gradually Eastwards to the meridian.—(*Chronicon Andegavense.*) Several authorities say that the comet appeared for only 2 weeks, from Oct. 18 to Nov. 1.—(Witichindus, *Annales.* Francofurti, 1621.) All remark that a great mortality amongst oxen occurred in the following year *in consequence* of the comet's apparition [?].

[311.] **943.** On Nov. 5 a comet appeared in the E.: its R. A. was greater than that of α Virginis by 9°. Its tail was 1 cubit long, and pointed to the W.—Ma-tuoan-lin; Williams, 54.) Comets were seen for 14 nights.—(*Annalista Saxo;* in Eccard's *Corpus Historicum*, Lipsiæ, 1723.)

[312.] **945.** "Theotilon, Bishop of Tours, set out from Laon to return to his diocese, but was overtaken on the road by the malady of which he died. He had just partaken of the Holy Sacrament, when a luminous sign was seen traversing the sky. This sign was a cubit long. Its brilliancy was such that it gave light in the middle of the night to those who were charged to conduct to Tours the body of the prelate by a journey of 200 miles."—(Frodoardus, *Chronicon.*) Pingré considers that, apart from other testimony, the duration determines this to have been "une veritable comète."—(*Comét.* i. 356.)

[313.] **956.** On March 13 a comet was seen in the cross of Orion. Its tail pointed towards the S.W.—(Ma-tuoan-lin; Williams, 54.) It is possible that "March 13" may not accurately represent the original, owing to a doubt attending the Chinese method of computation.

[314.] **959.** At the time of the death of the emperor Constantine Porphyrogenitus a gloomy and obscure star appeared for some time.—(Constant. Porph., *Incerti Continuatoris*, p. 289.) Constantine died on Nov. 9. It was seen from Oct. 17 to Nov. 1.—(Tackius, *Cœli anomalon, id est, de Cometis scriptum.* Gissæ-Hassorum, 1653.)

Biot has an extraordinary star in January, and another in February, 962: he assumes these to be one and the same, and both to be identical with No. 13 of the "calculated" comets.

[315.] **975** (i). In April a comet was seen in the E.—(Williams, 55.)

[316.] **975** (ii). A bearded comet was visible from August to October.—(Cedrenus, *Compendium Historiarum*, p. 683.) It was first seen on Aug. 3 in the sidereal division of δ Hydræ, between 7 and 9 hours of the morning; the tail was 40 cubits long. The comet traversed Cancer and came to the sidereal division of γ Pegasi, and lasted altogether 12 weeks, during which time it passed through 11 sidereal divisions.—(Gaubil.) It became visible on the 5th moon, which terminated on July 11.—(De Mailla, viii. 58.) There is much reason to believe that this comet is identical with the celebrated ones of 1264 and 1556. Presuming the PP. to have taken place at the end of July, the above accounts will all harmonise extremely well.—(Pingré, i. 357.)

[317.] **981.** A comet appeared in the autumn.—(Burkhardus, Monachus S. Galli, *Historia*, i., in Goldastus's *Alamannicarum Rerum.* Francofurti, 1606.)

[318.] **983.** On April 3 an extraordinary star appeared near β Leonis. More precisely, it was between β and η Virginis: it approached ν, ξ, π Virginis, and went to the N.—(Biot.*) A comet appeared.—(Lubienitz, &c.)

[319.] **985.** A comet appeared during the pontificate of John XVI.—(Platinæ, *De Vitis Summorum Pontificorum.* Coloniæ, 1540.)

[320.] **989** (i). On Feb. 10 a comet appeared to the N. of α and β Pegasi. It was 1° long, and lasted 14 days.—(Gaubil; *Annalista Saxo.*) Pingré seems to question the value of Gaubil's citation.—(*Comét.* i. 620.) Possibly the chronicle cited above refers to the 2nd comet of this year, the orbit of which has been calculated by Burckhardt.

[321.] 990 (i).* On Feb. 2 an extraordinary star appeared in the division of γ Corvi: it retrograded towards ν, κ, υ, φ Hydræ and disappeared, having travelled 40° in 10 weeks.—(Biot.)

[322.] 990 (ii). A star, with a long tail, appeared in the N. After some days it was in the W., and its tail extended to the E.—Romualdus Salernitanus, *Chronicon*, in Muratori's Collection, vol. vii.) It was seen in August—September in the W.—(Couplet.)

[323.] 995. On Aug. 10 a comet was seen.—(Hepidannus, *Annales*, in Bouquet's Collection, vol. vii; Florentius Vigorniensis, *Chronicon*.)

[324.] 998. On Feb. 23 a comet, 1 cubit long, was seen to the N. of α and β Pegasi. It lasted a fortnight.—(Couplet; De Mailla, viii. 131; Ma-tuoan-lin; Williams, 55.)

[325.] 1000. A comet appeared on Dec. 14 for 9 days. It frightened everybody. —Iperius, *Chronicon*, xxxiii.) A meteor appeared at the same time, and the majority of writers confound the one with the other. This may be the real explanation of the fact that a slight doubt hangs over the year as to whether it was 999 or 1000. Pingré thinks was clearly the latter.

[326.] 1003 (i). In February a comet was seen; it disappeared near the Sun, and was only seen for a few days a little before the rising of that body.—(Hepidannus, *Annales*.)

[327.] 1003 (ii). A comet appeared during the pontificate of John XVII.—(*Chronicon Nuremburgense*.) It lasted a long time.—(*Chronicon Stederburgense*.) It was discovered in China on Dec. 23, when it was situated in the sidereal divisions of μ Geminorum and θ Cancri. It approached very near θ, τ, ι, υ, φ Geminorum, passed by α, β Aurigæ, β Tauri, to the cross of Orion, and disappeared after 30 days. Its tail was 4 cubits long, and like a vase in shape.—(Ma-tuoan-lin; Williams, 56.) Some European writers refer to a comet in 1004, which is probably this one prolonged. Pope John was elected on June 13, and lived only till Dec. 7. So can there have been 2 comets between June 1003 and Dec.—Jan. 1003–4?

[328.] 1005. A comet was seen in the S.—(Alpertius, *De Diversitate Temporum*; in Eccard's Collection, vol. i.) It was in the W. in September, at the commencement of the night, and lasted 3 months. It shone with great brilliancy, and did not set till cock-crowing.—(Glaber Rudolphus, *Annales*, in Duchesne's Collection, vol. iv.) It was seen in China in September—October, within the circle of perpetual apparition. —De Mailla, viii. 158.) On Oct. 4 an extraordinary star appeared in the circumpolar regions near β, γ Draconis; it passed by some little stars between ψ Draconis and δ Ursæ Minoris to some little stars in Camelopardus, N. of Cassiopeia. It only lasted 11 days.—(Biot.*)

[329.] 1012. A comet of extraordinary grandeur was seen for 3 months in the Southern part of the heavens.—(Hepidannus, *Annales*.)

[330.] 1015. A comet was seen in February.—(Protospatas, *Breve Chronicon*, in Muratori's Collection, vol. v.) In China on Feb. 10, 1014, a comet was seen in the W.—(Williams, 64.) Probably one and the same comet, and some error in the year.

[331.] 1017. A comet, like a large beam, was seen for 4 months.—(Sigebertus, *Chronographia*, in Bouquet's collection, vol. iii; Gerbrandus, *Chronicon Belgicum*, ix. 8.) Hevelius says that it appeared in Leo, but gives no authority for this statement.

[332.] 1018. On Aug. 4 a comet appeared to the N. E. of (it would seem) ζ Ursæ Majoris; its was 3 cubits long, and went Northwards. It passed by ω and θ, ν, φ Ursæ Majoris, and thence Southwards—(Ma-tuoan-lin; Williams, 56)—by a route which Pingré says must have been erroneously stated. However, it is certain that a comet appeared this year in the Polar regions, and that it lasted about 6 weeks.—(Ditmarus, *Chronicon*, viii.) It is less certain that its length increased to 30°, and that passing Leo it disappeared in Hydra.

An extraordinary star appeared on June 10 to the N.W. of κ Leonis: it advanced rapidly by α Leonis to the vicinity of β Leonis: it touched β Virginis, and passing ι Leonis (or δ Virginis) came to the N.W. of ν, o, ξ, π Virginis. It lasted 11 weeks.—(Biot.*)

[333.] **1023.** A comet appeared in Leo during the autumn.—(Ademarus, *Chronicon*, in Bouquet's Collection, vol. x.) The original account contains much that is certainly fictitious.

[334.] **1024.** A comet appeared the year before the death of Boleslas I. king of Poland.—(Dlugossus, *Historia Polonica*. Francofurti, 1711.)

[335.] **1032.** On July 15 an extraordinary star appeared in the N. E. It approached β Leonis, and threw out a tail. On July 27 it disappeared.—(Biot.*) Cedrenus speaks of a brilliant star having passed from S. to N. this year.—(*Compendium Historiarum*, 730.)

[336.] **1033.** A comet, 2° long, appeared on March 5 to "the E. of the N. country" [N. E. ?].—(Ma-tuoan-lin.) It appeared on March 9 about the 10th hour of the night, and lasted till sunrise for 3 nights.—(*Fragmentum Historiæ Francorum*, i. and ii, in Bouquet's Collection, vol. viii.)

[337.] **1034.** A column of fire was seen in the E. in September. Its summit inclined towards the S.—(Cedrenus, *Compendium Historiarum*, p. 737.) It appeared between κ, υ, λ, μ, ϕ Hydræ et Crateris.—(De Mailla, viii. 199)

[338.] **1035** (i). On Sept. 15 a comet appeared in the sidereal divisions of ν Hydræ and α Crateris. It was $7\frac{5}{10}$ cubits long, and lasted 12 days.—(Ma-tuoan-lin; Williams, 56.) Possibly this is identical with the preceding. If 1035 is the right year, probably the column of fire was a meteor.

[339.] **1035** (ii). On Nov. 11 a comet, with a faint tail, appeared near α, β Piscium.—(Ma-tuoan-lin.) For Nov. 11, 1035, Williams (p. 56) reads Jan. 15, 1036.

[340.] **1041.** Comets appeared.—(Glycas, *Annales*, p. 316. Parisiis, 1660.)

[341.] **1042.** On Oct. 6 a comet appeared. Its motion was from E. to W., and it lasted through the month.—(Glycas, *Annales*, p. 319.)

[342.] **1046.** A comet appeared in the 15th year of Henry I. of France.—(Godellus, *Chronica*, in Bouquet's Collection, vol. xi.)

[343.] **1049.** On the morning of March 10, before sunrise, a comet was seen near β Aquarii, and α Equulei; it passed by the head of Orion, Musca, and the horns of Aries, and lasted 16 weeks.—(Gaubil.) "La route qu'on assigne a cette comète n'est pas naturelle."—(Pingré, i. 372.) Ma-tuoan-lin is scarcely more intelligible. Pingré is disposed to think that Gaubil has made a mistranslation. The words rendered "head of Orion" and "Musca," united into one word, closely resemble the word standing for "the circumpolar region." This affords a certain amount of explanation for the incongruity, and Williams seems to adopt it in saying (p. 56) that the comet passed from the sidereal division of β Aquarii through the circumpolar regions to the sidereal division of β Arietis.

[344.] **1056.** In July—August a comet appeared in the circumpolar regions.—(De Mailla, viii. 245.) It seems to have passed southwards to Hydra, but Gaubil places it in the head of Orion when first seen. Ma-tuoan-lin agrees with De Mailla. It was 10 cubits long, and on Sept. 25 had disappeared. [N.B. The head of Orion is *Tsoui*, the other region *Tse-ouey;* pronunciation nearly identical, hence possibly a confusion. See note to No. 343, *ante*.] Williams's account (p. 57) is simply that a comet was seen within the circle of perpetual apparition, and that it passed through the "seven stars" [of Ursa Major ?].

[345.] **1058.** "The death of Casimir, king of Poland, was announced by a comet, which appeared for several nights." (Hennenfeld, *Annales Silesiæ*.) It lasted the whole of Easter week.—(Morigia, *Chronicon*, i., in Muratori's Collection, vol. xii.)

[346.] **1060.** Shortly after the death of Henry, king of France, a comet with a long tail appeared in the morning.—(Wilhelmus Malmesburiensis, *De Gestis Regum Angliæ*.) Henry died on Aug. 29.

[347.] 1067. A comet appeared at the death of Constantine Ducas.—(*Chronicon Andegavense.*) This event happened in May.

[348.] 1069.* On July 12 an extraordinary star appeared in the sidereal division of γ^2 Sagittarii: on July 23 it traversed γ, δ, ϵ, λ Sagittarii.—(Biot.)

[349.] 1070.* On Dec. 25 an extraordinary star appeared in Aries, below Musca.—(Biot.)

[350.] 1071–8. During the reign of Michael Parapinatius comets frequently appeared.—(Curopalatæ, *Excerpta e Breviario Historico*, p. 856. Parisiis, 1647.)

[351.] 1075 (i). A great comet was seen in Morocco, during July—August. (Ibn Abi Zer'a, *Annales Regum Maurit.*: *Ast. Nach.*, No. 2811. vol. cxviii. Nov. 9, 1887.)

[352.] 1075 (ii). On Nov. 17 a comet, 3° long, appeared in the S. E. in the middle of the sidereal division of γ Corvi. The day following, the tail was bifid and curved. On Nov. 19 its length was 5 cubits; on Nov. 20, 7 cubits, and it pointed towards η Corvi. On Nov. 29 the comet entered the Hyades and disappeared.—(Ma-tuoan-lin; De Mailla, viii. 285.) For "Hyades" Williams (p. 59) reads "the clouds."

[353.] 1080 (i). On Jan. 6 a comet passed over the sidereal division of μ Scorpii.—(Williams, 64.)

[354.] 1080 (ii). On Aug. 10 a comet, 10 cubits long, appeared to the S. of Coma Berenicis: it was curved, and pointed to the S. E. Its R. A. exceeded that of γ Corvi by 8° or 9°. On Aug. 13 it moved towards the N. W. [Pingré does not understand what is meant], and its R. A. exceeded that of α Crateris by 9°. On Aug. 15 it was 3 cubits long, and curved, and penetrated Coma Berenicis. On Aug. 20 the comet passed very near α, γ Leonis. On Aug. 24 it could not be seen.—(Ma-tuoan-lin; Williams, 59.)

[355.] 1080 (iii). On Aug. 27 a comet, which Ma-tuoan-lin regards as the preceding again visible, appeared in the middle of the sidereal division of ν Hydræ; it lasted till Sept. 14. Pingré is the authority for disinguishing these comets.—(*Comét.* i. 625.)

[356.] 1096. On Oct. 7 a comet like a sword appeared in the Southern part of the heavens.—(*Annalista Saxo.*)

[357.] 1097 (ii). On Dec. 6 a comet was seen in the W.—(Williams, 64.)

[358.] 1098. On June 3, "the night of the capture of Antioch," a comet shone out with great brilliancy.—(Robertus, *Historia Hierosolymitana*, v.)

[359.] 1101. On Jan. 31 a large comet appeared in the W. after sunset.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

[360.] 1106. A splendid comet appeared this year. It was first seen on Feb. 4, within $1\frac{1}{2}$ feet of the Sun, between the 3rd and 9th hours of the day. In Palestine it became visible on Feb. 7, and in China 3 days later. On Feb. 7 it was in the sidereal division of β Andromedæ, and it passed through the sidereal divisions of β Arietis, α Muscæ, the Pleiades, and ϵ Tauri. The comet remained visible for 7 or 8 weeks, and had a tail 63° long.—(Matthæus Paris, *Historia Major;* Gaubil; Ma-tuoan-lin; Williams, 60; and many others.) [Williams treats Ma-tuoan-lin's account as pertaining to a meteor, but this is out of the question under the circumstances.]

[361.] 1109. In December a comet appeared near the Milky Way, with a tail pointing towards the S.—(Hemingfort, *Chronica*, i. 33.)

[362.] 1110. On May 29 a comet, with a tail 6 cubits long, was seen in the sidereal division of β Andromedæ and β Arietis. It went Northwards towards the Pole, and then became visible throughout the night, and ultimately disappeared in the R. A. of about 4^h.—(*Chronica Regia S. Pantaleonis;* Ma-tuoan-lin; Williams, 60.)

[363.] 1113. A great comet appeared in May.—(Matthæus Paris, *Historia Major;* Matthæus Westmonasteriensis, *Flores Historiarum.*)

[364.] 1114. A comet at the end of May. It lasted several nights, and had a long tail.—(Henricus Huntingdoniensis, *Historia;* *Annales Waverleienses.*)

[365.] **1115.** An extraordinary star in April—May, near α, β, γ Leonis. It had a long tail.—(De Mailla, viii. 377; *Annales De Margan . . . a tempore S. Edwardi Confess.*) Probably a comet, though no mention is made of movement.

[366.] **1125.** A comet preceded the death of Uladislas, king of Bohemia.—(Dubravius, *Historia Bojemica,* xi. Hanoviæ, 1602.)

[367.] **1126** (i). In June—July a large comet was seen within the circle of perpetual apparition. It passed from α Herculis towards θ, ϕ Ursa Majoris.—(De Mailla, viii. 443.) These Chinese positions will not harmonise with the statement of the Latin historians (Sicardus, *Chronicon,* in Muratori's Collection, vol. vii.), unless we suppose the comet to have been in Ursa Major at the end of July, or even at the beginning of August.—(Pingré, i. 392.) Williams (p. 61) dates this comet for May 20, and thinks the reading α Ursæ Minoris to be preferred to α Herculis.

[368.] **1126** (ii). In the moon beginning on Dec. 15 a great comet was seen in China, near the horizon. (De Mailla, viii. 447; Ma-tuoan-lin; Williams, 61.)

[369.] **1131.** In September—October a great star appeared.—(Ma-tuoan-lin; Williams, 61.)

[370.] **1132** (i). On Jan. 5 a comet was seen.—(Ma-tuoan-lin; Williams, 61.)

[371.] **1132** (ii). On Oct. 2 a comet appeared; on Oct. 7 it was in the sidereal division of α Muscæ; on Oct. 27 it had disappeared.—(Ma-tuoan-lin; Florentius Vigorniensis, *Chronicon*—continuation.) Williams (p. 61) makes this comet to have been visible from Aug. 14 to Sept. 3.

[372.] **1133.** On Sept. 29 a comet was seen near θ, ν, ϕ Ursæ Majoris.—(Williams, 65.)

[373.] **1138.** In August—September a comet appeared.—(De Mailla, viii. 524; Biot.*)

[374.] **1142–3.** In December—January a comet appeared.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

[375.] **1145.** On April 15 a comet appeared.—(*Cal ndarius Ambrosianæ Bibliothecæ,* in Muratori's Collection, vol. ii.) It is not easy to reconcile the conflicting accounts of its course. In China it was first seen in the E. on April 24; on May 14 it was in the sidereal division of δ Orionis [and must have had a considerable North latitude, or it would not have been visible.—Pingré,] and had a tail, pointing to the N. E., 10° long. On June 4 it was like a star; on June 9 it was stationary between α Hydræ et Crateris, and remained visible till July 14.—(Gaubil.) On April 26 it came from the constellations of the E. country. [These are probably the first 7 of the Chinese zodiac, commencing at α Virginis.—Pingré.] After 50 days it disappeared. On July 13 it reappeared in the cross of Orion, and lasted 15 days.—Ma-tuoan-lin, who adds that a comet was seen on June 4 [when the above was still visible].) Hind considers the former to be certainly *Halley's comet,* and that it passed PP. on April 29. Possibly Gaubil's "May 24" and the position assigned thereto is apocryphal. Pingré's note was made before Ma-tuoan-lin's account was in his possession: he professes himself unable to decide. But the comet of July 15 might have been different from the 50-day one which disappeared on June 15; in which view of the matter the latter might have been Ma-tuoan-lin's June 4 comet. Williams (p. 62) is very brief.

[376.] **1146.** A comet was seen for a long time in the W.—(*Chronica Regia S. Pantaleonis.*)

[377.] **1147** (i). The emperor Conrad set out in May for Palestine; his departure was preceded by a comet.—(*Historia Episcoporum Virdunensium.*) On Feb. 8 a comet, 10° long, appeared in the E. for 15 days.—(Gaubil.) On Jan. 6 (or 11) a comet appeared in the S.W. of the sidereal division of α Aquarii and ϵ, θ Pegasi.—(Ma-tuoan-lin.) This writer says that on Feb. 12 (or 17) another comet appeared in the N. E. in the sidereal division of ϵ Aquarii, and that on March 5 (or 7) it had ceased to be visible.—(Williams, 62.)

[378.] **1147** (ii). About Aug. 20 in Japan a comet was seen.—(Kaempfer, *Histoire du Japon,* II. iv.)

[379.] **1152** *or* **1156**. Ma-tuoan-lin, the former; Gaubil and the Great Annals of China, the latter. On August 15 a comet was seen in the middle of Gemini; the next day it was like Jupiter, and 2° long. On the day *Kouey-tchéou*, or Aug. 22, 1152, a comet passed near θ, τ, ι, υ, ϕ Geminorum.—(Ma-tuoan-lin.) On July 26 a comet, 10° long, was seen in the feet of Gemini. On the day *Kouey-tchéou*, or Aug. 2, 1156, it was near θ Geminorum.—(Gaubil.) Williams, (p. 62) renders Ma-tuoan-lin's year as 1151, and some other difficulties occur in his account.

[380.] **1155**. On May 5 a comet was seen.—(*Chronicon Monasterii Admontensis.*)

[381.] **1162**. On Nov. 13 a great comet appeared in the square of Pegasus: it went towards χ and ψ Aquarii. Its tail was more than 10° long.—(Gaubil.)

[382.] **1165** (i *and* ii). Two comets appeared this year in August before sunrise; the one in the N., the other in the S.—(*Chronica de Mailros.*)

[383.] **1181**. In July a comet was seen.—(*Chronica de Mailros.*) It appeared shortly before the death of Pope Alexander III.—(Cavitellius, *Annales Cremonenses.*) This happened on Aug. 30. Gaubil mentions a new star, seen on Aug. 11, under the footstool of Cassiopeia. It disappeared after 156 days. Nothing is said as to its having had any movement. Between Aug. 6, 1181 and Feb. 6, 1182, an extraordinary star was visible. From the division of ζ Andromedæ it passed over some little stars in Camelopardus, N. of the head of Ursa Major.—(Biot.*)

[384.] **1188**. A comet was seen all over England. It signified the death of Henry the King.—(*Annales Cambriæ.*)

[385.] **1198**. In November a comet appeared for 15 days. It announced the death of King Richard I. of England.—(Radulphus Coggeshale, *Chronicon Anglicanum.*) Richard died on April 6, 1199.

[386.] **1204**. In the year of the capture of Constantinople by the Latins a great comet appeared.—(Sicardus, *Chronicon.*)

[387.] **1208**. A comet appeared.—(*Chronicon Weichenstephenense.*) A brilliant star like a fire appeared after sunset for 2 weeks; the Jews regarded it as a sign of the approach of the Messiah.—(Cæsar Heisterbacensis, *Excerpta Historiarum Memorabilium.*)

[388.] **1211**. In May a comet was seen for 18 days in Poland.—(M. Cromerus, *Polonia*, vii. Coloniæ Agrippinæ, 1589.)

[389.] **1214**. In March two terrible comets were seen.—(Boethius, *Scotorum Historia*, xiii.) No doubt a single comet with a considerable North Declination, which would accord with the statement of one comet preceding and the other following the Sun. One author associates the comet with a solar eclipse which happened in 1215.

[390]. **1217**. "In the autumn, after sunset, we saw a beautiful sign; a star which soon sank below the horizon. This star was turned towards the South, pointing a little Westwards. Its position faced the crown of Ariadne."—(Conradus, Abbas Urspergensis, *Chronicon.*) Pingré understands the above expression to mean that the comet's azimuth was as much W. of S. as that of Corona Borealis was W. of N.—(*Comét.* i. 398.)

[391.] **1222**. In the months of August and September a fine star of the 1st magnitude, with a large tail, appeared. When first seen it was near the place where the Sun sets in December.—(*Annales Waverleienses*, &c.) It was observed in China between the feet of Virgo, Arcturus, and Coma Berenicis. It disappeared on Oct 8.—(Gaubil.) On Sept. 25 it came from η Boötis. The tail was 30 cubits long. The comet traversed the sidereal divisions of α, β, &c. Libræ, β, δ, &c. σ, α, &c. Scorpii, and then perished, after remaining in sight for 2 months.—(Ma-tuoan-lin.) With this comet we lose the invaluable guidance of this able Chinaman. For "Sept. 25" Williams (p. 63) reads "Sept. 15."

[392.] **1223**. Early in July a comet appeared in the Western heavens in the evening twilight. It was looked upon as the precursor of the death of Philip Augustus King of France.—(*Chronique de France*, MS.) Most probably *Halley's comet.*—(Hind.)

[393.] **1226.** On Sept. 13 a comet appeared between η, τ, ν Boötis and Coma Berenicis. It pointed towards α Boötis. On Sept. 12 (*sic*) it disappeared.—(Williams, 65.)

[394.] **1227.** A comet appeared.—(Matt. Paris., *Abbrev. Chronic.*)

[395.] **1230.** A comet appeared.—(Dubravius, *Historia Bojemica*, xv.) On Dec. 15 an extraordinary star appeared between Ophiuchus and Serpens below the Stars F and D in the head of Cerberus. On March 30, 1231, it had disappeared.—(Biot.)

[396.] **1232.** On Oct. 17 a comet, 10° long, was seen in the sidereal division of α Virginis. On the 12th day of its apparition it was 20° long. On the 16th day it was close to the Moon. On the 27th day, at the 5th watch, it reappeared in the S.E., and was 40° long; it was finally lost sight of on Nov. 14.—(De Mailla, ix. 173; Gaubil; Williams, 63.) It began to disappear on Dec. 2.—(Biot.) The date Nov. 14 is determined by Pingré, but it seems open to question. It must be added that Biot states that it (the comet) was *not* seen on the "16th day" during the moonshine: he likewise doubts whether the "12th day" (and consequently the other days) means that day of the moon or of the comet's apparition; Pingré says the latter, "sans doute." Another entry by Williams (p. 65) assigns this comet to 1237, Sept. 21, bnt the preponderance of testimony is in favour of 1232.

[397.] **1239.** A comet was seen in February.—(*Monarchiæ Sinicæ Synopsis Chronologica.*) Shortly after the birth of Edward, son of Henry III. of England, at the commencement of 1238, a splendid comet appeared for several days before sunrise.—(Polydorus Vergilius, *Anglica Historica*, xvi.) Edward was certainly born in 1239, so no doubt the Chinese date is the correct one.

[398.] **1240.** On Jan. 25 a comet was seen; at the end of that month it was observed in the W. During February it continued to appear in the same quarter of the heavens, its tail pointing to the E.—(Rolandinus, *Chronicon*, v. 1, in Muratori's Collection, vol. viii.) In China, on Jan. 31, a comet was seen near α Pegasi; on Feb. 23 it passed near α and β Cassiopeiæ. On March 31 it began to disappear.—(Biot.)

[399.] **1250.** A comet appeared in December, about the time of the death of the Emperor Frederick II.—(*Gesta Trevirensium Archiepiscoporum*, No. 266.)

[400.] **1254.** In November a comet appeared.—(Petrus Pictaviensis, *Chronica*, MS.)

[401.] **1262.** A comet appeared for several months.—(Crusius, *Annales Suevici*, III. ii. Francofurti, 1595.)

[482.] **1263.** In July—August a comet was seen in the E.—(Gassarus, *Annales Augustburgenses.*) Of doubtful authenticity, the writer not being contemporary.

[403.] **1265.** A comet appeared at the beginning of autumn and lasted till the end of that season. It was visible from midnight.—(*Chronicon Mellicense*, in Pez's Collection, Lipsiæ, 1721.) It was first seen in September.—(Franciscus Pipinus, *Chronicon*, in Muratori's Collection, vol. ix.) It is just possible that there were 2 comets this year; one visible July—September, the other September—November.

[404.] **1266.** In August, before daybreak, a comet was seen near the sign Taurus.—(Gregoras, *Historia Byzantina.* Parisiis, 1702.) A visibility of 3 months may be inferred.

[405.] **1269.** In the 20th year of the reign of Alexander, King of Scotland, a very fine comet appeared towards noon [sub meridiem].—(Boethius, *Scotorum Historia*, xiii.) "Towards the S." would be a good rendering.—(Pingré, i. 415.) It was observed in the E. in August and September.—(Malvecius, *Chronicon Brixiense*, VIII. lxxviii, in Muratori's Collection, vol. xiv.)

[406.] **1273.** On Dec. 5 a new star appeared in the Hyades. It moved through Auriga, past θ, ϕ, υ Ursæ Majoris, ϵ, σ, ρ Boötis to Arcturus, and remained visible 3 weeks.—(Gaubil.)

[407.] **1274.** Three days before the death of Thomas Aquinas, a comet appeared.—(Guillelmus De Thoco, *Vita S. Thomæ Aquinatis*, x. 60.)

[408.] **1277.** On March 9 a comet, 4° long, was seen in the N. E.—(Gaubil; Williams, 66.)

[409.] **1285.** In this year a great comet appeared; its tail pointed towards the N. W.—(Ptolemæus Lucensis, *Historia Ecclesiastica*, XXIV. xvii.) On April 5 a very brilliant star was seen.—(Pontanus, *Bohemia Pia*, i. Francofurti, 1608.)

[410.] **1293** *or* **1294.** In February 1293 or January 1294 a comet was seen in the circumpolar regions; it passed through the square of Ursa Major.—(Couplet; Gaubil.) On Nov. 7, 1293, a comet appeared as above. It was 1 cubit long, and lasted a moon.—(Biot; Williams, 67.)

[411.] **1298.** Celestial signs announced the death of Beomond, Archbishop of Treves [*ob.* Dec. 9, 1299]. In the preceding year a comet was seen, during 12 consecutive nights, at about the 3rd hour of the night. Its head was in the N. and its tail trended Southwards.—(*Gesta Trevirensium Archiepiscorum.*)

[412.] **1301** (ii). Before Christmas a comet was seen in the W. after sunset. It set before midnight. and lasted 15 days. On Dec. 1 it was in Aquarius and Pisces.—(Ricobaldus, *Compilatio Chronologica.*)

[413.] **1304.** On Feb. 3 a comet was seen in the sidereal division of α Pegasi; it passed towards the circumpolar regions, and by the tail of Cygnus and Cepheus; it lasted 11 weeks.—(De Mailla, ix. 483.) Its tail was more than 1 cubit long, and pointed towards the S. E. when discovered; afterwards it pointed towards the N. W. On Feb. 3 it was in the 11th degree of α Pegasi; it subsequently swept π Cygni, χ Andromedæ, and entered the circumpolar regions.—(Biot; Williams, 68.)

[414.] **1305.** Three days before and 3 days after Easter, or from April 15 to April 21, a long tail was seen.—(Botho, *Chronica Brunswicenses.*)

[415.] **1313.** From April 13 or 20 a comet was seen in the E. part of the sidereal division of μ Geminorum. It remained visible a fortnight.—(Biot; Gaubil; Williams, 68; Massatus, *Historia Augusta*, xv. 4, in Muratori's Collection, vol. x.)

[416.] **1314.** In October [?] a comet appeared in the latter part of [the sign?] Virgo, towards the N.—(Paulus Cygnæus, *Chronicon Citizense.*) The accounts are very vague and contradictory. One writer dates its visibility from May 1, and says that it remained visible for 6 months.—(Pontanus, *Historia Gelrica*, vi.)

[417.] **1315.** On Oct. 29 a comet was discovered in the region lying around β Leonis. On Nov. 28 it was in the circumpolar regions. It then traversed 15 sidereal divisions from that of γ Corvi to that of γ Pegasi. It remained in sight till March 11, 1316.—(Gaubil; Biot; Williams, 68.) European writers say that 2 comets were visible from Dec. 1315 to Feb. 1316. The first was much larger than the second.—(Hegecius, *De Stellâ Novâ anni* 1571, *&c.*) The N. P. D. of the larger one, on Dec. 25, at 17^h, was 18° 38′; on Jan. 15, at 17^h, it was only 9° 49′.—(Massatus, *De Gestis Italicorum*, vii. 14, in Muratori's Collection, vol. x.) Those who speak of the second comet say that it appeared in the E.—(*Chronicon Rotomagense.*) Can it be that after all there was only 1 comet?

[418.] **1334.** In August a comet, with a tail 7½ feet [degrees?] long, was seen.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

[419.] **1337** (ii). A comet was seen in Cancer during the visibility of the Great Comet of this year. It lasted 2 months.—(Giovani Villani, *Chroniche*, XI. lxvi, in Muratori's Collection, vol. xiv.) The Great Comet was visible for 3 months or more, from May. Chinese writers seem to speak of 2 comets. The lesser one passed from α, β, η Cassiopeiæ to Corona Borealis, and lasted from May 4 to July 31.

[420.] **1338.** On April 15 a comet was discovered; the Sun being then in Taurus, the comet was in Gemini. Its movement was from W. to E. with a N. Declination. It followed the Sun, and set about midnight. On April 17 it was in 24° of Gemini. From a note by Friar Giles it appears that its latitude was then 17° or 18° N. It remained in sight a fortnight or more.—(*Chronicon Rotomagense.*)

[421.] **1340.** On March 24 a comet was discovered in the 7th degree of the sidereal division π Scorpii. It went slowly to the N.W. "When first seen it was in the latter part of Libra; then it retrograded at the rate of 5° a day, till it came to

Leo, where it disappeared." It was visible 32 days.—(De Mailla, ix. 576; Gaubil; Williams, 71; Gregoras, *Historia Byzantina,* XI. vii. 5. Fol. Parisiis, 1702.) Biot's chronicler states that this comet was in shape like a *bale of cotton*!

[422.] **1345.** At the end of July a comet appeared near the head of Ursa Major; it advanced day by day to the zodiac, and when it reached the latter part of the sign Leo, where the Sun was, it disappeared.—(Gregoras, *Historia Byzantina,* XV. v. 6.)

[423.] **1347.** In the reign of Louis of Bavaria a comet appeared for 2 months. In Italy it was seen during 15 days in August in 16° of Taurus, and the head of Medusa. —(*Chronicon Nuremburgense.*)

[424.] **1356.** On Sept. 21 a comet was seen precisely in the E. at 17° in the sidereal division of ν Hydræ; it remained visible till Nov. 4. When discovered it was near α Leonis, and had a tail 1 cubit long which pointed to the S. W.—(Gaubil; Biot; Williams, 71.)

[425.] **1360.** A comet was seen in the E. for a few days from March 25.—(*Chronicon Zwetlense,* in Pez's Collection; De Mailla, ix. 633.) For March 26 Williams (p. 71) reads March 12.

[426.] **1362** (ii). On June 29 a comet, with a tail 1 cubit long pointing to the S. E., was seen in the circumpolar regions. Its R. A. was $2\frac{90}{100}°$ greater than that of β Capricorni [Biot, $9\frac{90}{100}°$]. It went to the S.W. On July 6 the luminous envelope swept θ Draconis; on Aug. 2 the comet had disappeared, having lasted 5 weeks.—(Gaubil; Williams, 72.) De Mailla says that the comet appeared near α and β Capricorni, and that its tail was more than 100 feet long.—(*Hist. Gén.* ix. 640.) This account is altogether irreconcileable with Gaubil's. Can there have been 3 comets this year, or does not De Mailla rather refer to the first comet, the orbit of which has been calculated, and therefore appears in Catalogue I.?

[427.] **1363.** On March 15 a comet appeared in the E. It was visible during the current moon.—(Biot; Williams, 72.)

[428.] **1368.** In February, March and April, a comet appeared in the evening in the W. or N. W. to the N. of the Pleiades.—(Couplet; Walsingham, *Historia Anglica.*) On Feb. 7 a comet was seen in the sidereal divisions of the Pleiades and ϵ Tauri. On April 7 a comet was seen in the N.W. between τ, κ, ρ and α, γ, η Persei; the tail was 8° long, and pointed towards θ, υ, ϕ Ursæ Majoris. It ultimately disappeared to the N. of α and β Aurigæ.—(Biot; Williams, 74.)

[429.] **1371.** On Jan. 15 a very great comet was seen in the N. Its tail was directed towards the S.—(Bonincontrius, *Annales,* in Muratori's Collection, vol. xii.)

[430.] **1373.** In April—May, three [?] comets entered the circle of perpetual apparition.—(Biot.)

[431.] **1376.** On June 22 a great comet appeared in Cetus near ι, θ, η; it traversed δ, ϵ, μ, ν Piscium, ν Persei, entered the circle of perpetual apparition, swept θ, υ, ϕ Ursæ Majoris, and directing itself towards δ, ϵ, π, ρ Draconis, entered the sidereal division of ν^1 or 39 Hydræ. It disappeared on Aug. 8.—(Biot*; Gaubil; Williams, 87.)

[432.] **1380.** On Nov. 10 a comet appeared.—(Cygnæus, *Chronicon Citizense.*)

[433.] **1382** (i). On March 30 a comet appeared.—(Botho, *Chronicon Brunswicense.*)

[434.] **1382** (ii). On Aug. 19 a comet appeared in that part of the heavens where the Sun sets in June. It lasted for 15 days, and was seen 2 hours before sunrise, though these two latter statements may be open to doubt.—(*Annales Vicentini;* in Muratori's Collection, vol. xiii.)

[435.] **1382** (iii). In December a comet appeared in the W. for more than a fortnight.—(Walsingham, *Historia Anglica.*)

[436.] **1388.** On March 29 a star appeared in the Eastern part of the sidereal division of γ Pegasi.—(Biot*; Williams, 88.)

[437.] **1391.** In May a small comet appeared near the stars of Ursa Major. Its tail was not very bright.—(*Annales Forolivienses ;* in Muratori's collection, vol. xxii.) Biot says that 2 comets appeared on the 23rd of this month ; one entered the circle of perpetual apparition between α and ι Draconis and passed to the S. of θ Draconis, and the other passed by the N. of Camelopardus and swept the Pole-star.—(Williams, 74.)

[438.] **1399.** In November a star of extraordinary brilliancy was seen; its tail was turned towards the W. ; it lasted only a week.—(F. E. Du Mezerai, *Histoire de France.* Abridged ed., 4to. Paris, 1668.)

[439.] **1402** (i). About Feb. 8 a comet appeared, which afterwards became very brilliant, so much so as to be visible in the daytime. It lasted till the middle of April. It appears to have been in the S. W. when first seen, setting in the W. At the beginning of March it was in Aries, and was seen from $2\frac{1}{2}^h$ before till 3^h after sunset, or even later. Subsequently it was seen in the N.W. On Palm Sunday, March 19, its size was prodigious.—(Walsingham, *Historia Anglica ;* Poggius, *Historia Florentina,* in Muratori's Collection, vol. xx ; Ebendorfferus, *Chronicon Austriacum,* in Pez's Collection.) The daylight visibility of this comet extended to 8 days, the longest instance of the kind on record.

[440.] **1402** (ii). From June to September an immense comet was visible in the W. —(Ducas, *Historia Byzantina.* Fol. Parisiis, 1649.) The descriptions are long, but contain nothing of practical value. The comet was visible in the daytime, and *perhaps* it attained its maximum brilliancy at the end of August. This or the preceding was regarded as the sign, by some even the cause, of the death of John Gallius Visconti, Duke of Milan.—(*Annales Forolivienses.*)

[441.] **1406.** Sometime between January and June a comet appeared in the W. for several nights.—(*Chronica Bremenses.*)

[442.] **1407.** On Dec. 15 a comet was seen.—(Biot ; Williams, 75.)

[443.] **1408.** On Oct. 16 a comet, or something like one, was seen.—(Antonius Petrus, *Diarium Romanum ;* in Muratori's Collection, vol. xxiv.)

[444.] **1430** (i). A terrible comet appeared on Aug. 24.—(Kaempfer, *Histoire du Japon,* II. v.) On Sept. 9 a great star appeared near α, β Canis Minoris. It lasted 26 days.—(Biot* ; Williams, 88.)

[445.] **1430** (ii). On Nov. 14 an extraordinary star was seen to the S. of δ, ϵ, μ, ν Piscium. It went to the S. E., passed near ι, θ, η Ceti, and disappeared in 8 days.—(Biot* ; Williams, 89.)

[446.] **1431.** On May 15 or 27 a comet, 5 cubits long, was observed in the Eastern part of the sidereal division of μ Geminorum.—(Gaubil ; Biot ; Williams, 75.) Is this identical with the "star" seen on Jan. 3 near μ Eridani which lasted 15 days ?—(Williams, 89.)

[447.] **1432.** On Feb. 2 a comet, about 10° long, appeared in the E. It swept the region near α Cygni, and went to the S. E. On Feb. 12 it began to disappear. On Feb. 29 another comet [doubtless the same after its PP.] became visible for 17 days. —(Biot ; Williams, 75.) It lasted 8 days, and its tail pointed from E. to N.—(Michovius, *Chronica Polonorum,* IV. xlvii.) Williams has some doubt whether for Feb. 29 we should not read Oct. 26, in which case there were 2 comets in 1432.

[448.] **1436.** James I. of Scotland was assassinated on Feb. 20, 1437. During the previous autumn a comet was seen,—(Boethius, *Historia Scotorum.* xvii.)

[449.] **1439** (i). On March 25 a comet was seen in the sidereal division of ν Hydræ, It went to the W., and swept ξ, ψ, ω Leonis and κ, ξ Cancri. It then went to the N., and passed into the sidereal division of θ Cancri. On April 2 it had a tail 5 cubits long.—(Biot.) Williams (p. 76) makes the tail 50 cubits long.

[450.] **1439** (ii). On July 12 a comet, about 10° long, appeared near the Hyades for 7 weeks. It pointed to the S. W.—(Biot ; Williams, 76.) Perhaps the preceding, after its PP. A comet, lasting 1 month, was seen this year in Poland, between the W. and the S.—(Dlugossus, *Historia Polonica,* xii.) In Japan also a comet was seen. —(Kaempfer, *Histoire du Japon,* II. v.)

[451.] **1444.** A comet appeared about the time of the summer solstice : on June 15, according to others.—(G. Fabricius, *Rerum Germaniæ...Memorabilium.*) On Aug. 6 a comet, 10° long, was seen to the E. of β Leonis. It became longer day by day till Aug. 15, when it entered the sidereal division of α Virginis, and disappeared.—(Biot ; Williams, 76.)

[452.] **1452.** In March—April a comet appeared near the Hyades.—(Gaubil.) On March 5 a comet appeared in the sidereal division of ϵ Tauri.—(Biot ; Williams, 77.)

[453.] **1453.** On Jan. 4 an extraordinary star appeared near the nebula in Cancer. It went slowly Westwards.—(Biot * ; Gaubil ; Williams, 89.)

[454.] **1454.** In the summer a comet like a sword became visible in the evenings after sunset.—(Phranza, *Chronicon De Rebus Constantinopolitanis*, viii. Fol. Venetiis, 1733.)

[455.] **1457** (i). At the commencement of the year a comet appeared.—(Pontanus, *Historia Gelrica,* ix.) Between Jan. 14 and 23 a comet, ½ cubit and more long, appeared in the sidereal division of ϵ Tauri. It went to the S. E.—(Biot ; Williams.) Celoria on the strength of some information given in a MS. by one Toscanelli preserved in the National Library at Florence calculated an orbit for this comet as given at the end of Catalogue I., *ante.*—(*Ast. Nach.*, vol. cx. No. 2627. Nov. 3, 1884.)

[456.] **1457** (ii). In June a comet appeared in the 20th degree of Pisces.—(*Chronicon Nuremburgense,* and others.) The conclusion seems unavoidable that there were 2 comets in June, and that this is not identical with the one computed by Hind. This doubt has been confirmed by Celoria, who found in Toscanelli's MS. materials for the orbit given at the end of Catalogue I., *ante.* (*Ast. Nach.*, vol. cx. No. 2627. Nov. 3, 1884.)

[457.] **1457** (iv). On October 26 a comet ½ cubit long appeared in the sidereal division of α Virginis. It passed near ζ and θ Virginis.—(Williams, 78.)

[458.] **1458.** On Dec. 24 a star appeared in the sidereal division of α Hydræ; it went to the W. till Dec. 27, when it became faint: it was near α, γ, ζ, η Leonis. On Dec. 31 it had a tail ½ cubit long ; it "attacked" λ (or ϕ) Cancri. On Jan. 12, 1459, it disappeared in the Eastern part of the sidereal division of μ Geminorum.—(Biot * ; Williams, 89.)

[459.] **1458** *or* **1459.** Probably the former. In June—July a comet appeared in Taurus (?).—(De Mailla, x. 236 ; A. Rockenbackius, *Exempla Cometarum.*)

[460.] **1460.** James II., King of Scotland, was killed on Aug. 3, 1460. The evening before, a very brilliant comet with a long tail was seen.—(Boethius, *Historia Scotorum*, xviii.)

[461.] **1461.** On July 30 a white star appeared near *k, l, g* Tauri Poniatowskii. On Aug. 2 it transformed itself into a vapour, and disappeared.—(Biot *.) On Aug. 5, a comet was seen in the E. It pointed to the S. W. It entered the sidereal division of μ Geminorum. On Sept. 2 it began to disappear.—(Williams, 79.) These accounts do not seem reconcileable.

[462.] **1463.** In this year (no month assigned) a comet was seen near τ and v Virginis.—(Gaubil.)

[463.] **1464.** In the spring a comet was seen in Leo.—(Gaubil.)

[464.] **1465.** In March and April a comet was seen, with a tail 30° long, in the N. W.—(Biot ; Williams, 79 ; Kaempfer, *Histoire du Japon*, II. v.)

[465.] **1467.** In October a comet was seen above Pisces, "as if it had been formed in Cancer." Rainy weather prevented its being often seen.—(*Chronicon S. Ægidii Brunswicensis.*) Pingré does not seem to attach much credibility to this account.

[466.] **1468** (i). On Feb. 24 a comet was seen near Ursa Major.—(Gaubil.)

[467.] **1471.** In the autumn, in Poland, a very great comet was seen. It rose before sunrise. It was in the latter part of Virgo and in Libra, and lasted a month.—(Michovius, *Chronica Polonorum*, IV. lxii.)

[468.] **1476.** From Dec. 1476 to Jan. 5, 1477, a small comet was visible.—(Ripamontius, *Historia Urbis Mediolanensis*, vi.)

[469.] **1477.** In December a comet appeared.—(*Chronica Bossiana.*)

[470.] **1478.** In September a great comet appeared.—(*Chronica Bossiana.*)

[471.] **1495.*** On Jan. 7 a star was seen near θ, ρ Ophiuchi; it travelled with a slow motion till Feb. 20, when it entered the division of α Aquarii.—(Biot.)

[472.] **1502.*** On Nov. 28 a star appeared near Pyxis Nautica. From the division of υ^1 Hydræ it directed itself towards that of α Crateris. On Dec. 8 it disappeared.—(Biot.)

[473.] **1503.** At about the time of the Festival of the Assumption of the Virgin Mary [Aug. 15] a comet was seen. Its tail pointed towards the E.—(*Chronicon Waldsassense.*)

[474.] **1505.** A comet was seen in Aries. It lasted only a few days.—(Mizaldus, *Cometographia.* 4to. Parisiis, 1549.)

[475.] **1512.** In March and April a comet appeared.—(*Chronicon Magdeburgense.*)

[476.] **1513.** From Dec. 1513 to Feb. 21, 1514, a comet was visible. It passed from the end of the sign Cancer to the end of that of Virgo, and was seen all night. —(Vicomercatus, *Commentarii in lib. Aristotel. Meteor.*, xlix.)

[477.] **1516.** The death of Ferdinand the Catholic, King of Arragon (Jan. 23), was announced by a comet, which lasted many days.—(P. Bizarus, *Historia Genuensis*, xix. 446.) Others say that the comet was only visible for a few days.

[478.] **1518.** During the nights preceding April 6 a pale comet was seen above the citadel of Cremona.—(Cavitellius, *Annales Cremonenses.*)

[479.] **1520.** In February a comet appeared.—(Biot; Williams, 82.)

[480.] **1521.** In April a comet with a short tail appeared in the latter part of Cancer.—(Vicomercatus, *Comment. in Aristot.* xlix; Lubienitz.) Month and position depend only on modern authority. On Feb. 7 a star appeared in the S. E.; it was 6° or 7° long: it went from E. to W., and divided itself.—(Biot.*) Gaubil alludes to this, but his description was supposed by Pingré to belong to Jupiter.

[481.] **1522.** A comet was seen in the W.—(Mizaldus, *Cometographia*, II. xi.) No month given.

[482.] **1523.** In July a comet was seen near α Ophiuchi.—(Biot; Williams, 82.)

[483.] **1529.** In February a long star traversed the sky. This phenomenon renewed itself in August.—(Biot.*) European writers mention a comet in August, but Pingré considers that their descriptions belong to an aurora.—(*Comét.*, i. 486.)

[484.] **1530.** On Nov. 30 a comet was seen.—(Conradus Urspergensis, *Chronicon.* Fol. Argentorati, 1609.)

[485.] **1532.** A comet appeared in the spring.—(Gaubil.) On March 9 a star with a tail appeared in the S. E. After 19 days it disappeared.—(Biot*; Williams, 92.)

[486.] **1534.** A comet appeared in July.—(Cavitellius, *Annales Cremonenses.*) On June 12 a star was seen near π Cygni, κ Andromedæ, &c.; it passed by θ Andromedæ, and entering ν, ξ, o, π Cassiopeiæ, disappeared after 24 days.—(Biot*; Williams, 92.)

[487.] **1536.** On March 24 a star was seen near β, γ Draconis. It went Eastwards, and, passing to the W. of δ, ϵ, π, ζ Draconis, came to the Milky Way, and disappeared on April 27.—(Biot*; Williams, 92.)

[488.] **1538.** On Jan 17 P. Apian saw a comet, with a tail 30° long, in 5° of Pisces, with a latitude of 17° N. On the 22nd Gemma Frisius observed it in 9° of Pisces, with a latitude of 11° N.—(Pingré, *Comét.*, i. 495.)

[489.] **1539.** On April 30 a comet, with a tail 3° long, was seen. It remained visible for 3 weeks, and swept α and γ Leonis.—(Biot; Williams, 83.) On May 11 (?)

Gemma Frisius observed it in 5° of Leo, with a latitude of 12° N. On May 17, at 10^h in the evening, its position, according to Apian's observations reduced by Pingré, was 20° of Leo, with a latitude of $4\frac{1}{2}$° S.—(Pingré, *Comét.*, i. 500.)

[490.] **1545.** A comet was seen for several days. No month is given.—(Aretius, *Brevis Cometarum Explicatio.*) On Dec. 26 a comet appeared near β, γ Draconis; it entered the sidereal division of δ Sagittarii, and returned to the N. E. It disappeared at the end of the Moon.—(Biot*; Williams, 92.)

[491.] **1554.** On July 23 a comet was seen, which passed from δ to θ, v, ϕ Ursæ Majoris, and thence to α Serpentis. It lasted 4 weeks.—(Biot; Williams, 83.)

[492.] **1557.** In October, the Sun being in Libra, a comet was seen in the W., in Sagittarius.—(J. Camerarius, *Cometæ.* 8vo. Lipsiæ, 1558.) On Oct. 22 it was seen near λ Ophiuchi; it pointed to the N. E. It lasted till the next moon.—(Biot.) For 'Oct. 22' Williams reads 'Oct. 10,' and for 'N. E.' he reads 'N. W.'

[493.] **1560.** In December a comet appeared for a month.—(J. A. Thuanus, *Historiæ sui temporis*, xxvii. 11. Fol. London, 1733.)

[494.] **1569.** In November a comet was seen in Ophiuchus and in the signs Sagittarius and Capricornus. Its movement in longitude equalled the extent of these 2 signs, and it remained visible till Nov. 19.—(Kepler, *De Cometis*, 114.) It lasted from Nov. 9 to Nov. 28.—(Biot; Williams, 84.)

[495.] **1578.** On Feb. 22 a star as large as the Sun appeared.—(Biot*; Williams, 92.) European writers mention a comet and a hairy star, the latter on April 1. As Tycho Brahe's comet of 1577 remained visible till January 1578, Pingré thinks that that is the object described as the comet of 1578: the hairy star of April he considers to have been a meteor.

[496.] **1579.** "On the 10 of October (some say on 7) appeared a blazing star in y^e^ South, brushing towards y^e^ East, which was nightly seene diminishing of his brightness until y^e^ 21st of y^e^ same month."—(Stowe, *Chronicles.*)

[497.] **1591.** On April 3 a comet, 1 cubit long, was seen. It traversed the sidereal divisions of α Aquarii, α Pegasi, and γ Pegasi, increasing in length to 2°. On April 13 it entered the sidereal division of β Arietis.—(Biot; Williams, 85.)

[498.] **1604.** On Sept. 30 a large star like a ball appeared in the sidereal division of μ^2 Scorpii. It vanished in the S. W. in November. On Jan. 14, 1605, it reappeared in the S. E. About March it became dim.—(Biot*; Williams, 93.)

[499.] **1609.** A great star appeared in the S. W. The tail had 4 rays.—(Biot*; Williams, 93.)

[500.] **1618** (ii). Between Nov. 10 and 26 a comet was seen by Figueroes at Ispahan, coincidently with the apparition of comet iii. of this year. In consequence of the comet's Southerly motion the head was not generally, if at all, seen in Europe—only the tail. Kepler and Blancanus were the chief observers who saw the latter. Kepler *guessed* that on Nov. 10 the nucleus was in 16° of Scorpio, with a latitude of 8° S.; and that on Nov. 20 it was near the head of Centaur. At Rome the tail was seen to be 40° long on Nov. 18. It was last seen on the 29th. The observers (Jesuits) note that in 11 days the proper motion of the tail caused it to pass over 24° from Crater towards α Hydræ.—(Pingré, *Comét.*, ii. 57.) On Nov. 24 a white vapour 20 cubits long was seen in the S. E. It extended across the sidereal division of γ Corvi. It entered the sidereal division of α Crateris and disappeared after 19 days. (Williams, 93.) The Chinese record "a star like a white flower" as being visible on Dec. 5 of this year. It may be well to mention here that Cooper, in his *Cometic Orbits* (p. 77), appears to have fallen into a mistake relative to the comets of this year, which others have copied. He gives the elements of the iii^rd^ comet, and appends notes referring to the ii^nd^ and iii^rd^ as if they were one and the same object.

[501.] **1619.** In February a comet was seen in the S. E.: it was 100 cubits long, curved and pointed.—(Biot; Williams, 87.)

[502.] **1625.** From Jan. 26 to Feb. 12 a comet was observed by Schickhardt in Eridanus and Cetus.—(*Astronomische Nachrichten*, vol. ii. No. 31. April 1823.) It was Olbers who rescued this comet from oblivion.

[503.] **1628.** A comet appeared, mentioned by Ripamontius.—(*Astronomische Nachrichten*, vol. xii. No. 277. April 29, 1835.)

[504.] **1630.** A comet appeared; also mentioned by Ripamontius, and by him associated with a pestilence.—(*Astronomische Nachrichten*, vol. xii. No. 277. April 29, 1835.)

[505.] **1639.** On Oct. 27 a comet with a small tail was seen in Canis Major by Placidus de Titis.—(*Astronomische Nachrichten*, vol. viii. No. 171. January 1830.) In the autumn a comet was seen in the sidereal division of δ Orionis.—(Biot; Williams, 87.)

[506.] **1640.** On Dec. 12 a comet was seen.—(Biot; Williams, 87.) Perhaps it is to this comet that allusion is made by Evelyn, who speaking of the comet of 1680 says that one was seen about the trial of the Earl of Strafford in 1640.—(*Diary*, ed. Bray, London, 1850, vol. ii. p. 154.)

[507.] **1647.** On Sept. 29 a comet was seen soon after sunset in Coma Berenicis. Its longitude was 188° and its latitude + 26°. It was 12° long and lasted one week, traversing Boötes, Northwards of Arcturus, to Corona Borealis, in a line sensibly parallel to the equator.—(Hevelius, *Cometographia*, p. 463.)

[508.] **1666.** Robert Knox in a book on Ceylon published at Utrecht in 1692 says that the tail of a comet was seen in Ceylon in 1666.—(*Monatliche Correspondenz*, vol. xxviii. p. 428.)

[509.] **1699** (ii). On Oct. 26 Gottfried Kirch observed a faint comet in the poop of Argo; in longitude 122° 34′, and latitude − 40° 38′. It was visible to the naked eye, and its motion was sensibly Southwards. Kirch was unable to find it on any subsequent night.—(*Miscellanea Berolinensia*, v. 50.)

[510.] **1702** (i). Numerous navigators in the Southern hemisphere report seeing a comet between Feb. 20 and March 1. On Feb. 28 the tail was 43° long. At 8 P.M., in latitude 15° 10′ N., and longitude 116° 45′ E. of Teneriffe, the comet bore S. of W. 20° 30′, altitude 8° 40′. On all occasions it was seen in the evening, after sunset. Maraldi at Rome saw the tail for several days at the end of February and the beginning of March.—(Struyck, *Vervolg van de Beschryving der Staarts Sternen.* 4to. Amsterdam, 1753, p. 50.)

[511.] **1732.** On Feb. 27 a comet was seen above Spica Virginis by Hanow, probably at Danzig.—(*Monatliche Correspondenz*, vol. xxviii. p. 430.)

[512.] **1733.** On May 17 and 18 a comet was seen by several navigators off the Cape of Good Hope, bearing N.W. ¼W. It was observed for more than an hour, until it went below the horizon.—(Struyck, *Vervolg*, p. 61.) Its place was R.A., $6^h\ 5^m$: Decl. + 18° 35′. The comets of 1807 and 1881 (iii.) cannot have been identical with it.—(Oudemans, *Copernicus*, vol. i. p. 207.)

[513.] **1742** (ii). On April 11, in the morning, a comet was seen in the S.E. by several Dutch navigators at sea in the Southern ocean. On April 14 the tail was 30° long.—(Struyck, *Vervolg.*)

[514.] **1748** (iii). On April 24 a Dutch navigator, at the Cape of Good Hope, saw a comet, at the beginning of Aries, rise in the E. ¼N.E. at 4^h A.M. This is probably the comet, rendered invisible at the Cape by a Northerly motion, which Kindermanns saw on April 28, at 2^h A.M., at an elevation of 8° above the horizon, in a straight line with (it would seem) δ and η Trianguli and the brightest star of Aries, in Longitude 80°, Latitude + 28°, and Declination + 50°. On May 3, between 11^h and midnight, the comet was near Perseus, and circumpolar.—(Struyck, *Vervolg*, p. 100.)

[515.] **1750.** Between Jan. 21 and 25 Wargentin observed a comet below ε and θ Pegasi.—(*Tables Astronomiques de Berlin*, i. 35.)

[516.] **1770.** Returning from observing the Transit of Venus at Wardöhrs, Hell and Sainovics saw at Copenhagen on March 19, at 11 P.M., a comet in the North-East. It was searched for in vain at the Copenhagen Observatory, March 20 to 26, but, as pointed out by Olbers (*Ast. Nach.*, vol. xii., Nos. 273, 275, Feb. 11, March 7, 1835), too early in the evening, as the comet was probably approaching the Sun and would rise later every evening.

[517.] **1783** (ii). On Dec. 18, 1783, Sir W. Herschel observed a nebula 1^m preceding δ Ceti, and $\frac{1}{2}°$ N. of that star. He describes it as "small and cometic." In his son's great *Catalogue of Nebulæ*, 1864, this object is set down as really a comet, not having been since found, though looked for.

[518.] **1808** (i). On Feb. 6 Pons discovered a small faint comet between the neck of Serpens and the needle pointer of Libra. It was only visible for 3 days, becoming lost in the moonlight. Its movement was rapid and towards the S.—(*Monatliche Correspondenz*, vol. xviii. p. 252. Sept. 1808: *Ast. Nach.*, vol. vii. No. 149. Jan. 1829.)

[519.] **1808** (iv). On July 3 Pons discovered a comet in Camelopardus: it was observed only on that night and July 5. Its position on July 3, at $15^h\ 4^m\ 26^s$ Marseilles M.T., was R.A. $3^h\ 10^m\ 10^s$, and Decl. + 56° 36′: on July 5 at $15^h\ 8^m\ 58^s$ the R.A. was $3^h\ 31^m\ 46^s$, and Decl. + 58° 19′.—(*Monatliche Correspondenz*, vol. xviii. p. 249. Sept. 1808.)

[520.] **1839**. On July 14 and 17 an extremely faint comet was seen at the Roman College. It was in Draco, and appeared like a double nebula, or as if divided into 2 branches. The following positions were taken: July $14^d\ 10^h\ 1^m$, R.A. $12^h\ 9^m\ 41^s$, Decl. + 70° 28·6′; July $17^d\ 10^h\ 6^m$, R.A. $11^h\ 50^m\ 27^s$, Decl. + 70° 39·3′.—(*Memoria . . . Osservazioni fatte . . . in Collegio Romano*, 1839, p. 38.)

[521.] **1846** (ix). On Oct. 18 Hind observed a comet in Coma Berenicis for more than an hour. Its altitude was small, and being in the morning twilight it was never seen again. Its exact position at $16^h\ 15^m\ 11^s$ G.M.T. was R.A. $11^h\ 59^m\ 49^s$, Decl. + 14° 59′ 32″. Its motion was increasing in R.A. at the rate of about 4^m a day, and diminishing in Decl. at the rate of about 11′ a day.—(*Month. Not.*, vii. 162. Nov. 1846.)

[522.] **1849** (iv). On Nov. 15, at sea, in the S. Atlantic, a comet was seen from the U. S. Ship *Maryland*, with a nucleus as bright as Mars, and with a tail, curved and pointing to the S.W., nearly 1° long. From the notes of Captain Horner, Mr. Hind worked out the following position: at $9^h\ 49^m$ G.M.T., R.A. $20^h\ 36{\cdot}6^m$, Decl. + 4° 18′.—(*Month. Not.*, x. 122 and 192. March, &c., 1850.)

[523.] **1854** (iii). On March 16 a bright nebulous object was seen by Brorsen. Its position at $8^h\ 15^m\ 34^s$ Senftenburg M.T. was: R.A. $2^h\ 30^m\ 12^s$, and Decl. + 1° 11·2′.—(*Ast. Nach.*, vol. xxxviii. No. 897. March 27, 1854.)

[524.] **1855** (ii). On May 16, whilst searching for Di Vico's comet, Goldschmidt at Paris found a comet in R.A. $21^h\ 41^m\ 45^s$, Decl. − 15° 38′, which he announced as positively the missing comet (*Ast. Nach.*, vol. xli. No. 978. Aug. 25, 1855). No confirmation of the discovery was obtained, and astronomers, though they did not doubt that *a* comet had been seen, decidedly doubted that it was the periodical comet of Di Vico which Goldschmidt had found. Twelve years afterwards Winnecke claimed to have cleared up the uncertainty by determining that the comet seen by Goldschmidt was a prior return of comet ii. of 1867 (*Ast. Nach.*, vol. lxix. No. 1645. June 20, 1867): but this theory has been distinctly disproved by Von Asten (*Ast. Nach.*, vol. lxxxii. No. 1962. Nov. 3, 1873.)

[525.] **1856** (i). In January a comet was seen in the N.W. sky at Panama.—(Letter in the *Morning Herald*. *Month. Not.*, vol. xvii. p. 114. Feb. 1857.)

[526.] **1856** (ii). On Aug. 7 an object, supposed to be a comet, was seen in Virgo by E. J. Lowe.—(*Month. Not.*, vol. xvii. p. 114. Feb. 1857.) A comet was also seen at Arequipa, in Peru, for a fortnight previous to Aug. 21 for 2 hours after sunset.—(Letter in the *Times*, Oct. 8, 1856.)

[527.] **1859** (i). In Feb. a very faint comet was seen by Slater, in R.A. $11^h\ 48^m$: Decl. + 19° 49′. He saw it again on May 7 and 22, when it had become fainter, not being visible with any aperature below $11\frac{1}{2}$ inches. Its movement was very slow, and seemed to be in a northerly direction.—(*Month. Not.*, vol. xix. p. 291. June 1859.)

[528.] 1860 (v). On November 14, Tuttle at Cambridge U.S. observed a very faint comet near the Pole-Star. It was not questioned till 8 years afterwards but that this was identical with comet iv. of 1860.—(*Ast. Nach.*, vol. lv. No. 1301. March 30, 1861: *ib.*, vol. lxxiii. No. 1734. Jan. 16, 1869: *ib.*, vol. lxxiii. No. 1740. Feb. 16, 1869: *ib.*, vol. lxxv. No. 1787. Jan. 12, 1870.)

[529.] 1865 (ii). *Encke's comet.* This object was discovered by Tebbutt at Windsor, N.S.W., on June 24. It was very faint, and was seen only on that occasion and on June 29. Its observed place on the 24th is noted to have differed very much from that assigned by calculation.—(*Ast. Nach.*, vol. lxv. No. 1551. Oct. 6. 1865.)

[530 and 531.] 1865 iii. and iv. (?). On Aug. 27, two comets were seen by [E. J.] Lowe at $8^h\ 30^m$ P.M. The position of the first was, R. A. $15^h\ 15^m$: Decl. $-3°\ 50'$. And of the second, R. A. $15^h\ 0^m$: Decl. $-7°\ 30'$. "From an account I see in the newspapers of a comet seen at $3^h\ 45^m$ A.M. in the E. '*three days ago*' [no date given!] I have little doubt this is one of the comets I saw in August."—(*Month. Not.*, vol. xxv. p. 278. Oct. 1865.) [This is a *very* slovenly record.]

[532.] 1871 (vi). On December 29, at $6^h\ 15^m$ Milan M.T., Tempel observed a faint comet in R.A. $19^h\ 51^m\ 32^s$: Decl. $+29°\ 56'$.—(*Ast. Nach.*, vol. lxxviii. No. 1872. Jan. 3, 1872.)

[533.] 1872. On Dec. 2, Pogson at Madras, in consequence of a telegram from Klinkerfues of Göttingen (in these words, "Biela touched Earth on Nov. 27; search near θ Centauri"), sought and found a comet. At $17^h\ 31^m$ Madras M.T. its R.A. was $14^h\ 7^m\ 12^s$: Decl. $-34°\ 45'$. It was "bright, circular, about $45''$ in diameter: a very decided nucleus, but no tail discernible in strong twilight and cloudy sky." On the following morning at $17^h\ 3^m$ the comet was seen again in R.A. $14^h\ 21^m\ 55^s$: Decl. $-35°\ 4'$. The description was, "bright, round, and about $75''$ in diameter. A short faint tail seen about $7{\cdot}4'$ in length." Bad weather and the advance of twilight rendered subsequent observations impossible. This was presumed to have been the long-lost *Biela's comet*, but the idea has been disproved by Bruhns.—(*Month. Not.*, vol. xxxiii. p. 116. Dec. 1872: *Ast. Nach.*, vol. lxxx. No. 1918. Jan. 16, 1873: *ib.*, vol. lxxxiv. No. 2204. Aug. 11, 1874: *ib.*, vol. lxxxvi. No. 2054. Sept. 10, 1875.)

[534.] 1880. On Aug. 11, Mr. L. Swift at Rochester, State of New York, saw a nebulous object in the field with the nebula H I 262. No motion could be detected during the period of an hour. Bad weather followed, and the object, whatever it was, was not seen again. Its position on Aug. 11 was somewhere about R.A. $11^h\ 28^m$; Decl. $+68°$.—(*Ast. Nach.*, vol. xcviii. No. 2334. Sept. 11, 1880.)

[535.] 1881. On May 12 a faint comet was seen by Barnard at Nashville, Tennessee, in R.A. $22^h\ 59{\cdot}3^m$, Decl. $+14°\ 24'$; that is, in the field with and very near α Pegasi. It was again seen on the following night, in R.A. $22^h\ 58{\cdot}9^m$, Decl. $+14°\ 36'$, but no trace of it could be obtained subsequently.—(*Ast. Nach.*, vol. c., No. 2384. July 26. 1881.)

[536.] 1883. On Dec. 25, and again on Dec. 27, a comet was seen with the naked eye in Tasmania, according to testimony seemingly trustworthy. Kreutz by collating the information given arrived at the following positions:—

	Local Time. h. m.	R. A. h.	δ °
Dec. 24	15 0	14·8	6
26	16 6	16·5	0

(*Ast. Nach.*, vol. cviii. No. 2591, May 8, 1884; Tebbutt, *Observatory*, vol. vii. p. 116, April, 1884.)

[537.] 1882. On the occasion of the Eclipse of the Sun on May 16 a comet was seen with the naked eye in Egypt near the Sun during the total phase by Trépied. Its existence was also recorded on several photographs taken by Lockyer. It was distant from the Sun about the amount of the Sun's diameter, and had a tail about $\frac{1}{2}°$ long. It was never seen again.—(*Ast. Nach.*, vol. cii. No. 2441, July 6, 1882: *Observatory*, vol. v. p. 209, July 1882: *Month. Not.*, vol. xliii. p. 206, Feb. 1883.)

[538.] 1884. On May 26, a faint object, assumed to have been a nebula, was found at the Vienna Observatory with the great 26-inch refractor in R.A. $17^h\ 40^m\ 48^s$;

Decl. + 35° 42′. It could not be found again on June 18, and may have been Tuttle's comet (1858, iii.) due at that time and in about that position.—(*Dun Echt Circular*, No. 84.) This last-named supposition seems to have been unfounded. (See p. 430, *ante.*)

[539.] **1889.** On Jan. 15, just before dawn, Brooks at Geneva, N.Y., found a faint comet in R.A. $18^h\ 4^m$; Decl. −21° 20′. It had a rapid Westerly motion, and could not be found on Jan. 20.—*Month. Not.*, vol. xlix. p. 327.)

OBJECTS RECORDED AS NEBULÆ, BUT WHICH MAY POSSIBLY HAVE BEEN COMETS.

614 H. R.A. for 1860: $2^h\ 44^m\ 6^s$: Decl. + 36° 55·7′: observed by Bessel. Looked for and not found by D'Arrest, who supposes it to have been a comet. This is assumed by Dreyer to have been a certain star, and not a nebula at all, much less a comet.—(*Notes to New Gen. Cat.*, p. 214.)

2094 H. R.A. for 1860: $10^h\ 17^m\ 5^s$: Decl. + 27° 43·9′: observed by Sir J. Herschel. Looked for 6 times and not found by Lord Rosse. "This then was a comet or a lost nebula." Schulhof, possibly under some misconception of date, remarks that at the time when this observation was made (but this is not stated in Sir J. Herschel's *G. C.*) Tuttle's comet should have been very close to the place given for the nebula, and that perhaps it was the comet which was seen on the occasion.—(*Ast. Nach.*, vol. cviii. No. 2592, May 13, 1884.) Dreyer thinks it was a nebula after all, and identical with H 2095.—(*New Gen. Cat.*, No. 3234.)

50 ♅ III. On March 19, 1784, Sir W. Herschel observed an exceedingly faint nebula, $3^m\ 15^s$ following 45 Canum, and 4^m South. Sir J. Herschel stated that he had found a memorandum that this nebula is lost, and was probably a comet. But Dreyer identifies it with one found by Bigourdan.—(*New Gen. Cat.*, No. 2661.)

3550 H. R.A. for 1860: $13^h\ 21^m\ 13^s$: Decl. + 6° 43·4′: observed by D'Arrest, but "not found again on Feb. 19, 1863. Sky perfectly clear. Perhaps a comet."—(Dreyer, *New Gen. Cat.*, No. 5160.)

Hevelius, in his *Prodromus Astronomiæ* (pp. 207 and 289), states that he once saw in the head of Hercules, near α, a nebula. This was searched for unsuccessfully by Messier. The nearest object is 901 ♅ II, but this would be quite beyond the reach of the telescopes used in the time of Hevelius, so it must have been a comet that he saw.—(Smyth, *Cycle*, ii. 385: Lynn, *Observatory*, vol. ix. p. 164, April 1886.)

BOOK V.[a]

METEORIC ASTRONOMY.

CHAPTER I.

AËROLITES.

Classification of the subject.—Aërolites.—Summary of the researches of Berzelius, Rammelsberg, and others.—Celebrated Aërolites.—Summary of facts.—Catalogue of Meteoric Stones.—Arago's Table of Apparitions.—The Aërolite of 1492.—*Of* 1627.—*Of* 1795.—*The Meteoritic Shower of* 1803.—*The Aërolite of* 1876 (*Rowton*).—*The Aërolite of* 1881 (*Middlesborough*).—*The Aërolite of* 1887 (*Soko Banja*).

THE phenomena of which I am now about to speak form a highly interesting and by no means unimportant branch of descriptive astronomy. They may conveniently be treated under 3 heads:—

1. Aërolites
2. Fireballs.
3. Shooting Stars,

Of all cosmical meteors those known as aërolites, meteorites, or meteoric stones, are the rarest, but nevertheless they are not so rare as to prevent satisfactory evidence being produced that such occurrences have happened from time to time. It is to Chladni that we owe much of our knowledge of this branch of the subject[b]. Many of these meteoric stones, which have fallen or been

[a] This Book has been revised and added to for this edition by Mr. W. F. Denning.

[b] See his work *Die Feuermeteore*. A large amount of information brought up to a recent date will be found in *An Introduction to the Study of Meteorites*, published by the British Museum Trustees, 8vo. Lond., 1886.

found in different parts of the world, have been subjected to chemical analysis by Berzelius, Rammelsberg, and others, whose deductions may be thus summed up :—

1. Meteoric stones are composed of elements all of which occur in terrestrial minerals.

2. Of the 70 or more elementary substances now known, 24 have been found in meteoric stones, namely:—oxygen, hydrogen, nitrogen, chlorine, sulphur, phosphorus, carbon, silicon, iron, nickel, cobalt, chromium, manganese, copper, tin, antimony, aluminium, magnesium, calcium, potassium, sodium, lithium, titanium, and arsenic.

3. The produce of a meteoritic shower may be divided into meteoric iron and meteoric stone.

4. Meteoric iron is an alloy that has not yet been certainly found to exist among terrestrial minerals, and is composed of iron with from 3 or 4 to 15 or 18 per cent. of nickel, and small quantities of cobalt, manganese, magnesium, tin, copper, and carbon.

5. Meteoric stone is composed of minerals found abundantly in lavas and trap-rocks (and consequently of volcanic origin), a variable proportion of meteoric iron being usually admixed.

The circumstances attending the fall of aërolites differ considerably on different occasions. Not unfrequently the fall is attended by a loud detonation; but we must not therefore infer that every detonating meteor is indeed an aërolite, without positive proof to that effect. History records instances of considerable damage having been done to life and property by the descent of these bodies: as, for instance, from a Chinese catalogue we learn that one which fell on Jan. 14, 616 B.C., broke several chariots and killed 10 men. The chronicle of Frodoard informs us that in the year 944 A.D. globes of fire traversed the atmosphere and burnt several houses. More recently, on the evening of Nov. 13, 1835, a brilliant meteor was seen in the department of Aisne (France). It traversed the country in a north-easterly direction, and burst near the castle of Lausères, setting fire to a barn and the stables burning the corn and cattle in a few minutes. A stony substance supposed to be an aërolite was found near the place after the occurrence. On March 22, 1846, at 3 P.M., a luminous sheaf, which traversed the air with great velocity and noise, fell on a barn in a village in the department of Haute Garonne, which instantly took fire and was destroyed, together with the stables adjoining and the beasts therein contained[c]. It is related that the Emperor Jehangir had a sword forged from a mass of meteoric iron which fell at Jahlindù in the Punjab, in 1620[d]. Some of these descriptions doubtless relate to veritable aërolites, but other alleged instances of falls of aërolites are, it may be supposed, merely records of electrical discharges.

From the above and other similar observations we conclude:—

1. That the fact is undoubtedly established, that from time to time masses of stone, of different sizes, and often of considerable weight, pass through space, and are frequently precipitated upon the Earth's surface.

2. That these bodies do not always strike the Earth in a vertical or nearly vertical direction, but that they more often fall in a direction very oblique to the plane of the horizon. This is ascertained by an inspection of the manner in which they penetrate the soil, which they often do to a considerable depth.

3. That they are originally endued with a very great velocity, bearing indeed a finite proportion to the velocities which are found to characterise the planetary members of the solar system. This velocity they soon lose by the effects of atmospheric resistance, and it is so much reduced by the time they reach the ground that their speed scarcely exceeds that of bodies falling under the influence of gravitation.

The Ancients seem to have been well aware of the phenomena of which I am now treating, inasmuch as several objects are mentioned by the classic writers as having fallen from heaven: for instance, the Palladium of Troy, an "image" of Diana at

[c] See Arago, *Ast. Pop.*, vol. iv. pp. 224–29, French ed., where numerous other instances are given. In the English edition this and other important meteor catalogues are unfortunately left out.

[d] *Phil. Trans.*, vol. xciii. p. 200. 1830.

Ephesus[e], and the sacred shield of Numa. The ideas of the Ancients relative to the supposed celestial origin of these things have often met with ridicule; but however fabulous the cases referred to may have been, still the Moderns have been compelled, though reluctantly, to admit the fact of the actual transmission of stony substances from Space on to the surface of the Earth. The following catalogue of some of the more important recorded falls of meteoric stones is founded on one given in M. Izarn's work[f].

Substance.	Period.	Place.
Showers of stones	About 650 B.C.	Rome.
Large stone	465 B.C.	River Negos, Thrace.
Three large stones	452	In Thrace.
Shower of stones	343	Rome.
Shower of iron	54	Lucania.
Shower of mercury	Date unknown	In Italy.
Mass of iron of 14 quintals	,,	Abakauk, Siberia.
Large stone of 260 lbs.	1492 Nov. 7 ...	Ensisheim, Upper Rhine.
About 1200 stones—1 of 120 lbs., another of 60 lbs.	1510	Padua, Italy.
Stone of 59 lbs.	1627 Nov. 27 ...	Mont Vasia, Provence.
Sulphurous rain	1646	Copenhagen.
Sulphurous rain	1658	Duchy of Mansfeld.
Shower of unknown matter	1695	Ireland.
Stone of 72 lbs.	1706 January ...	Larissa, Macedonia.
Shower of fire	1717 Jan. 4 ...	Quesnoy.
Shower of sand for 15 hours	1719 April 6 ...	In the Atlantic.
Shower of sulphur	1721 October ...	Brunswick.
Mass of stone	1750	Niort, Normandy.
Shower of stones	1753 July 3 ...	Plaun, Bohemia.
Two stones weighing 20 lbs.... ...	1753 September	Liponas, in Brest.
Two stones of 200 and 300 lbs. ...	1762	Near Verona.
A stone of 7½ lbs.	1768 Sept. 13 ...	Lucé, Le Maine.
A stone	1768	Aire, Artois.
A stone	1768	Le Cotentin.
Shower of stones	1789 July ...	Barboutan, near Roquefort.
Extensive shower of stones	1790 July 24 ...	Near Agen.
About 12 stones	1794 July 16 ...	Siena, Tuscany.
A stone of 56 lbs.	1795 Dec. 13 ...	Wold Cottage, Thwing, Yorks.
A stone of 10 lbs.	1796 Feb. 19 ...	In Portugal.
A stone of 20 lbs.	1798 March 12	Sules, near Ville Franche.
A stone of about 20 lbs....	1798 March 17	Sâle, Dep. of Rhone.

[e] This no doubt was merely a stone of no particular shape: certainly not a sculptured stone.

[f] *Des Pierres Tombées du Ciel, ou Lithologie Astronomique.* Paris, 1803.

Substance.	Period.	Place.
Shower of stones	1798 Dec. 19 ...	Benares.
Mass of iron, 70 cubic feet	1800 April 5 ...	America.
Many stones, the largest $8\frac{3}{4}$ lbs. ...	1803 April 26 ...	Near L'Aigle, Normandy.
Shower of stones	1807 Dec. 14 ...	Weston, Connecticut, U.S.
A stone of 1653 lbs.	1810...	Santa Rosa, New Grenada.
Shower of 200 stones	1812 May 22 ...	Stannern, Bohemia.
A stone of 203 lbs.	1821 June 15 ...	Juvinas, Ardèche.
A large stone	1843 Sept. 16 ...	Kleinwenden, Thuringia.
Shower of stones	1864 May 15 ...	Orgueil, France.
Stone of 6 cwt. and 1000 smaller ones	1866 June 9 ...	Knyahinya, Hungary.
Fragment of Iron weighing $7\frac{3}{4}$ lbs.	1876 April 20 ...	Rowton, Shropshire.
A stone of 3 lbs. $8\frac{1}{4}$ oz.	1881 Mar. 14 ...	Middlesborough, Yorkshire.

The 206 falls of aërolites, of which Arago knew the month of occurrence, were, according to him, distributed in the following manner through the 12 months of the year:—

Month	Number	Total	Month	Number	Total
January	14	99	July	23	107
February... ...	10		August	16	
March	22		September... ...	17	
April	15		October	18	
May	20		November.. ..	20	
June	18		December	13	

From an inspection of the above table it appears that the monthly average from December to June (16) is less than the monthly average from July to November (18), and that, moreover, the months of March, May, July, and November exhibit maximum numbers: and we also learn this general fact—that the Earth, in its annual course round the Sun, would seem to encounter a greater number of aërolites in passing from aphelion to perihelion, or between July and January, than in going from perihelion to aphelion, or between January and July.

It has been asserted to be a general rule that the area over which a shower of stones falls is oval, measuring from 6 to 10 miles in length by 2 or 3 in breadth, and, moreover, that the largest stones may be expected to be found at one extremity of the oval.

When found entire the stones are completely coated or glazed over with a thin dark-coloured crust formed from the molten substance of their surface fused by ignition in the fire-balls, the part which travelled foremost being sometimes distinguishable from that which was in the rear. Freshly-fractured faces have also been observed, and the pieces, 5 in number, of the well-crusted meteorite weighing 32 lbs. which fell at Butsura in India in 1861 were without difficulty fitted together by Maskelyne after an attentive consideration of the fractures. This is the more noteworthy from the fact that the pieces were picked up at places several miles apart. This instance of the disruption of a meteorite perhaps throws some light upon the circumstance that large fireballs are occasionally seen to break up into fragments as they disappear.

The circumstances connected with the occurrence which stands No. 8 in the catalogue (*ante*), are of more than ordinary interest, especially from its having been long considered a poetical romance of by-gone ages. The following narrative was drawn up at the time by order of the Emperor Maximilian, and deposited with the stone in the church at Ensisheim. "In the year of the Lord 1492, on Wednesday, which was Martinmas Eve, November 7, a singular miracle occurred; for between 11 o'clock and noon there was a loud clap of thunder, and a prolonged confused noise, which was heard at a great distance; and a stone fell from the air, in the jurisdiction of Ensisheim, which weighed 260 pounds; and the confused noise was, moreover, much louder than here. There a child saw it strike on a field in the upper jurisdiction, towards the Rhine and Jura, near the district of Giscano, which was sown with wheat, and it did no harm, except that it made a hole there; and then they conveyed it from that spot, and many pieces were broken from it, which the landvogt forbade. They therefore caused it to be placed in the church, with the intention of suspending it as a miracle; and there came here many people to see this stone. So there were remarkable conversations about this stone; but the learned said they knew not what it was; for it was beyond the ordinary course of nature that such a large stone should smite the Earth, from the height of the air, but that it was really a miracle of God; for, before that time, never anything was heard like it, nor seen, nor described. When they found that stone, it had entered into the Earth to the depth of a man's stature, which everybody explained to be the will of God that it should be found; and the noise of it was heard at Lucerne, at Vitting, and in many other places, so loud, that it was believed that houses had been overturned: and as the King Maximilian was here the Monday after St. Catherine's Day of the same year, his Royal Excellency ordered the stone which had fallen to be brought to the castle; and after having conversed a long time about it with the noblemen, he said that the people of Ensisheim should take it, and order it to be hung up in the church, and not to allow anybody to take anything from it. His Excellency, however, took two pieces of it, of which he kept one, and sent the other to Duke Sigismund of Austria; and they spoke a great deal about this stone, which they suspended in the choir, where it still is; and a great many people came to see it." This relic remained in the church for 3 centuries, and then it was temporarily removed, during the turmoil of the French Revolution, to Colmar, but it has since been restored[g]. A fragment of it is in the British Museum, and there is another piece at the Jardin des Plantes, at Paris.

The fall of the aërolite of 1627 (No. 10) was witnessed by the astronomer Gassendi: he states that when in the air it was apparently surrounded by a halo of prismatic colours. This being the only aërolite of the fall of which he had ever heard, he supposed that it was the result of a volcanic eruption in some one of the neighbouring mountains. Views similar to Gassendi's of the origin of aërolites were maintained even recently by Kesselmeyer, whose work on the geographical distribution of aërolites supplied an excellent list, with maps, of such occurrences up to a very recent date. Such views, it will not be necessary to remind the reader, cannot however now be held to accord with the known cosmical origin of these bodies.

The aërolite of Dec. 13, 1795 (No. 28), is interesting from the fact that it is one of the few instances recorded to have taken place in this country. A loud explosion, followed by a

[g] Bädeker says that this stone is now preserved in the Rathhaus. (*Rhine*, 9th Eng. ed., p. 282, 1884.)

hissing noise, was heard throughout a considerable portion of the surrounding district; a shock was also noticed, as if produced by the falling to the Earth of some heavy body. A ploughman saw the stone fall to the ground at a spot not far distant from the place where he was standing; it threw up mould on every side, and, after passing through the soil, penetrated several inches deep into the solid chalk rock. It fell on the afternoon of a mild but hazy day, during which there was neither thunder nor lightning[h].

One of the most extensive falls of meteoric stones on record was that which happened in Normandy on April 26, 1803 (No. 34). It appears that at about 1 P.M. a very brilliant fire-ball was seen traversing the country with great velocity; and, some moments afterwards, a violent explosion was heard, which was prolonged for 5^m or 6^m. The noise seemed to proceed from a small cloud, which remained motionless all the time but at a great elevation in the atmosphere; the detonation was followed by the fall of an immense number of mineral fragments, nearly 3000 being collected, the largest weighing $8\frac{3}{4}$ lbs., according to Arago. The sky was serene, and the air calm—an atmospheric condition that has sometimes been noticed, as well as opposite states of the weather, during the descent of aërolites[i].

On April 20, 1876, a mass of meteoric iron weighing between 7 and 8 lbs. fell at Rowton, a village near the Wrekin, in Shropshire. Shortly before 4 P.M. a sound like that of thunder, followed by reports as of cannon, shook the air, and was heard

[h] Howard, *Phil. Trans.*, vol. xcii. p. 174. 1802.

[i] A catalogue of 273 aërolites is given in Arago's *Ast. Pop.*, vol. iv. pp. 184–204. French ed. But larger numbers of aërolitic falls than this are now represented by specimens of meteorites preserved in the national museums of London, Paris, and Vienna; the British Museum alone possessing specimens of 370 different meteorites, of which about 240 were seen to fall. An important series of articles by Dr. W. Flight, in the *Geological Magazine*, 1875, 2nd Ser., vol. ii., supply a continuation of the list of Buchner and of other compilers. The first such catalogue was formed by Chladni, and a larger one by Kämtz (*Meteorologie*). Subsequently Buchner (*Die Meteoriten in Sammlungen*), Haidinger, Rammelsberg, Mrs. Sheppard, U.S. and others have furnished catalogues, a collection and discussion of which by R. P. Greg will be found in the *British Association Report*, 1860, with later supplements and revised tables of frequency of aërolites on different dates, in the volumes for 1867 (p. 414) and 1870 (p. 93).

(during rain showers) for many miles in that neighbourhood, but no fireball was observed. The iron mass was found nearly an hour afterwards in a meadow where it had buried itself in the earth to a depth of 18 inches; when dug out it was still quite hot.

The meteorite which fell at Sako-Banja in Servia exhibits a conglomerate structure or tufa resembling that presented by

Fig. 237.

METEORITE WHICH FELL AT SAKO-BANJA IN SERVIA, OCT. 13, 1877.

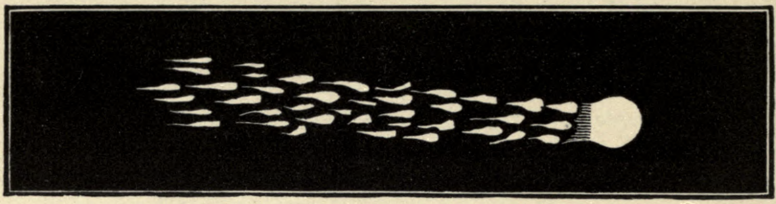
the ancient volcanos of Auvergne and of the valley of the Rhine.

The circumstances connected with the fall of the meteorite of March 14, 1881, near Middlesborough, were investigated by Prof. A. S. Herschel. At $3^h\ 35^m$ P.M., the air being calm and the sun shining brightly, 4 railway platelayers heard a rushing or roaring sound overhead, followed immediately by a thud on the ground. On proceeding to the spot, less than 50 yards distant, they found a round vertical hole, into which one of them thrust his arm and drew out the meteorite. The hole and also the meteorite were felt to be slightly warm about 3 minutes after the fall. Professor Herschel described the meteorite as of a low pyramidal or shell-like shape, and measuring 5 inches by 6 inches, and about 3 inches high. The grey basaltic stone of which it consisted was, as usual, completely enveloped in a thin black molten crust, which hid from the eye its true stony character, the latter being only visible here and there at its frayed edges. It was remarkable for the unusual depth and regularity of the indentations which its surface had received by heat and fusion in its passage through the air. This meteorite is now in the Library of the Literary and Philosophical Society of Newcastle[k].

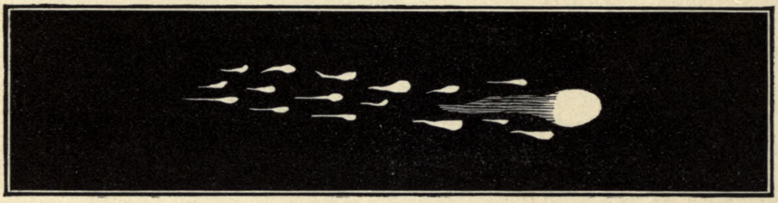
This is only the eighth case where the actual fall of an aëro-siderite or mass of meteoric iron has been observed, although many such masses have been found, some of them of large size, as at Krasnojarsk in Siberia, Atacama in Chili, Melbourne in Australia, and recently some colossal blocks on the Island of Disco in Greenland. At least one such meteoric mass has been discovered in this country; this was a meteorite weighing about 32 lbs., which was exhumed near Melrose in Scotland in the year 1827.

In addition to those mentioned above the following falls of meteoric iron have been actually observed:—Agram, Croatia (1751); Charlotte, Tenn., U.S. (1835); Braunau, Bohemia (1847); Victoria West, S. Africa (1862); Nidigullam, Madras (1870); Marysville, California (1873).

[k] *Observatory*, vol iv. p. 155. May 1881.

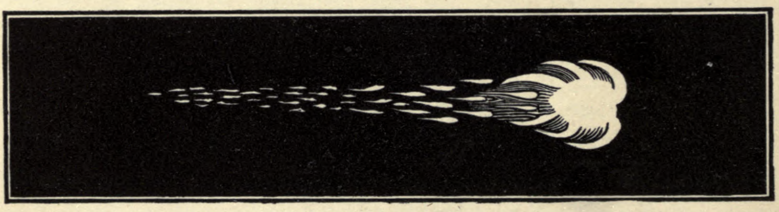


FIRST VIEW.

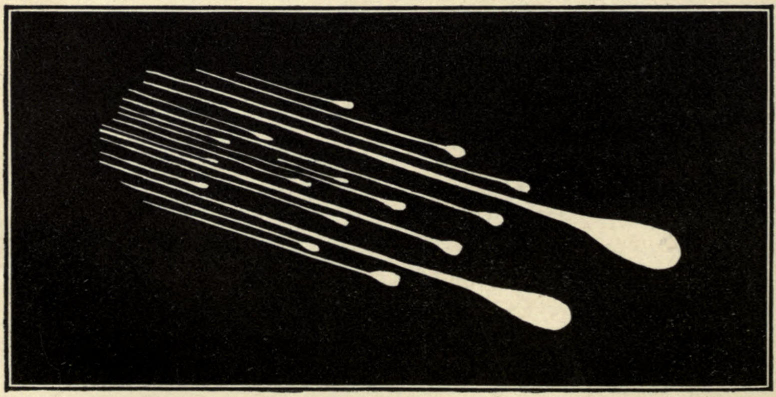


SECOND VIEW.

1783: Aug. 18. (*Sanby and Robinson.*)



1878: June 7. (*Denning.*)



1863: Oct. 19. (*Schmidt.*)

FIREBALLS.

CHAPTER II.

FIREBALLS.

General Description of them.—Fireball of Nov. 12, 1861.*—Monthly Table of apparitions.—Dates of greatest frequency.—Results of calculations with reference to these bodies.*

FIREBALLS[a] may either represent the larger class of shooting stars, or the aërolites described in the last chapter. There is no doubt that meteor showers like the Perseids, Leonids and many others, while yielding a considerable proportion of meteors of the smallest visible types, yet occasionally furnish Fireballs which are as brilliant and apparently as large as the Moon. They appear suddenly, and are usually noiseless, though at times a detonation is heard, and in these cases the phenomenon is probably aërolitic. Their form is generally pear-shaped. The slow-moving Fireballs usually evolve trains of sparks, but the swifter class project streaks of phosphorescence upon the sky, and these features (which may be taken to represent the consumed material thrown off by the incandescent nucleus) sometimes linger for many minutes after the first appearance, assuming irregular shapes and drifting slowly away from the place of apparition by the action of wind-currents high in the atmosphere.

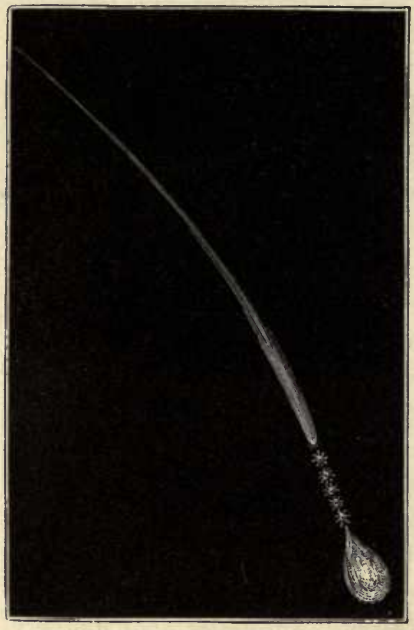
Fireballs are occasionally of great brilliancy, and appear so unexpectedly as to startle those who witness them. A good description of one of these bodies which fell on Nov. 12, 1861, is given by the Rev. T. W. Webb, and a part of his account

[a] The *British Association Report* for 1878 contains full instructions to observers of Fireballs and kindred phenomena. See also *Month. Not.*, R. A. S., vol. xliv. p. 297, April 1884.

may be quoted as a typical example of what is to be seen from time to time in connection with these objects:—

"About 5^h 45^m G.M.T. (with an uncertainty of 5^m or more) we were walking, a party of 3 persons, along a wide turnpike road, fully lighted by a moon 10 days old, when we were surrounded and startled by an instantaneous illumination, not like lightning, but rather resembling the effect of moonlight suddenly coming out from behind a dark cloud on a windy night; it faded very speedily, but on looking up we all perceived at a considerable altitude, perhaps 60° or 70°, a superb mass of fire sweeping onwards and falling slowly in a curved path down the W.S.W. sky. . . . Ruddy sparks, of the colour of glowing coals, were left behind at its smaller end, and its path was marked by a long pale streak of little permanency. Its termination, unfortunately, was concealed by boughs of trees, among which, however, it was traced till possibly some 10° above the horizon, but it had previously undergone a great diminution. . . . The whole duration may have been as much as 5 seconds. Its aspect was decidedly that of a liquefied and inflamed mass, and the immediate impression was that of rapid descent [b]."

Fig. 242.



METEOR OF NOV. 12, 1861. (*Webb.*)

Arago classified all the recorded instances of Fireballs according to their dates, and found that they were distributed as follows over the 12 months; a similar summary made up to a more recent date (1879) is also added for comparison [c]:—

	ARAGO.	TO 1879.		ARAGO.	TO 1879.
January	55	239	July	74	287
February	57	174	August	123	775
March	48	186	September	64	273
April	52	234	October	77	292
May	50	163	November	90	551
June	43	172	December	80	289
Jan. to June =	305	1168	July to Dec. =	508	2467

[b] Letter in the *London Review*, November 16, 1861.

[c] *Observatory*, vol. iii. p. 127, September 1879.

The numbers exhibit a great excess of these phenomena in the last half of the year. The most prolific months are August and November: the large number recorded in these months is partly due to the circumstance that meteor observers have devoted their chief attention to those months owing to the occurrence of the Perseids, Leonids and Andromedes.

It is found that at certain definite epochs of the year Fireballs are unusually numerous. The following appear to be the best defined dates for their observation:—

Jan. 2, 21, 31.	July 11, 20–21, **25–30**.
Feb. 3, **7**, 10.	Aug. 3, 5, **7–13**, 15, 19–22.
March 1, 2, 4.	Sept. **1–2**, **6–7**, 11–13, 25.
April **11–12**, **19–20**.	Oct. 13, 15, 17–18, 22, 24, 29.
May 2, 4, 15, 31.	Nov. **1–2**, **4**, **6–9**, **11–15**, **19**, **27**.
June **6**–7, 12, 29–30.	Dec. **8**–9, **11–12**, **21**.

The dates printed in heavier type have proved especially rich in Fireballs.

Though a very insignificant proportion of the observed Fireballs discharge aërolites upon the Earth's surface, it is probable that the two phenomena are intimately associated. Aërolites have occasionally been precipitated without any prior warning, in the form of luminous exhalations; an instance occurred on Sept. 16, 1843, at the fall of the great aërolite of Kleinwenden[d]. It is singular that during meteor storms, such as those of Nov. 13, 1866, and Nov. 27, 1872, none of the many thousands of fragments which entered our atmosphere were observed to reach the earth. This has been adduced as an argument against the theory of affinity between aërolites and ordinary meteors. On Nov. 27, 1885, however, during the recurrence of the Biela meteor storm, a piece of meteoric iron fell at Mazapil in Mexico; and there is strong evidence to show that this aërolite was a veritable fragment of Biela's comet!

Many Fireballs have formed the subjects of computation as to their distances, sizes, and velocities, but owing to the peculiar nature of these phenomena, their unexpected appearance, and the

[d] *Compt. Rend.*, vol. xxv. p. 627 (Nov. 2, 1847).

difficulty of securing perfectly accurate observations, the following results must be considered as mere approximations.

1. As to the extreme heights during visibility:—

GREATEST KNOWN.	Miles.	LEAST KNOWN.	Miles.
1868 Sept. 5	460·0	1879 Feb. 22	5·5
1844 Oct. 27	318·1	1879 Feb. 24	6·5
1718 Mar. 19	297·5	1846 Mar. 21	7·5

2. As to absolute diameter:—

GREATEST KNOWN.	Feet.	LEAST KNOWN.	Feet.
1841 Aug. 18	12,795	1852 April 2	105
1718 Mar. 19	8,399	1846 July 23	321
1837 Jan. 4	7,216	1850 July 6	705

3. As to velocity per second:—

GREATEST KNOWN.	Miles.	LEAST KNOWN.	Miles.
1850 July 6	47·22	1718 March 19	1·67
1844 Oct. 27	44·74	1807 Dec. 14	2·80
1842 June 3	44·74	1676 Mar. 31	3·11

The average velocity of a considerable number of meteors computed by Prof. A. S. Herschel is 35 miles per second.

The estimated diameters of Fireballs are usually much in excess of the real values. The absolute dimensions attributed to several large meteors in the above table must therefore be received with caution. The nucleus of a Fireball during combustion has a flaming aspect, and the glare invariably accompanying it creates an exaggerated impression of its size. Their velocities are also liable to considerable errors, as there are grave difficulties in the way of determining the exact durations of their flights, save in exceptional instances when the speed is slow and the observer is sufficiently prepared for the event to be able to time it carefully.

The average heights of Fireballs are less than the average heights of shooting stars[e]. A comparison of many recorded results gives the following relative figures:—

	At appearance.	At mid-course.	At disappearance.
Fireballs	69 miles	49½ miles	30 miles.
Shooting Stars ...	80 ,, ...	67 ,, ...	54 miles.

[e] *Month. Not.*, vol. xlviii. p. 113, January 1888.

It is evident that the brighter forms of meteoric display occur in a lower region of the atmosphere than that of the fainter class of these phenomena.

There are certain meteor showers which apparently yield a large proportion of Fireballs [f].

As a very recent example of observations followed by computation the following may be cited. On Nov. 13, 1888, Denning at Bristol and Backhouse at Sunderland each observed a fireball, which on a comparison of the accounts proved to be one and

Fig. 243.

1 2

CURIOUS FORM OF TRAIL LEFT BY THE FIREBALL OF OCTOBER 19, 1877.

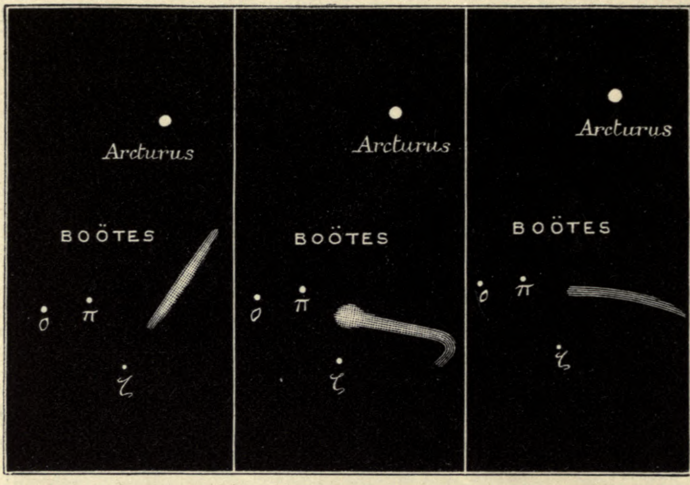
1 First effect. 2 Second effect (10 min. later).

the same object. Backhouse states that at 17^h 19^m he became suddenly aware of a bright flash, and, a few seconds later, he discovered an unusually intense Meteor-streak lying amongst the stars of Boötes and about 5° below Arcturus. It was estimated as 4° long at first, and proved very durable, for it remained in sight for 9^m, and exhibited during that time some alteration

[f] A table of the radiant points of these will be found in the *Monthly Not.*, vol. xliv. pp. 298–9, April 1884. A catalogue of 584 Fireballs is given in Arago's *Ast. Pop.*, vol. iv. pp. 230–79, French Ed. See also some important summaries by Greg in the *B. A. Reports* for 1860, 1867 (p. 414), and 1870 (p. 93).

both in shape and position. The places were carefully noted and recorded. Denning's observations were so far less satisfactory in that at Bristol the Meteor was seen much nearer the horizon, but the salient features were so similar that there can be no doubt about the identity of the two objects.

Fig. 244.



$17^h\ 19^m$. $17^h\ 22\frac{1}{4}^m$. $17^h\ 28^m$.

TRAIL LEFT BY THE FIREBALL OF NOV. 13, 1888.

The details of the observations need not be given, but a summary of them yields the following results:—

Beginning of Meteor (Bristol)	at 65 miles.
Beginning of Light Streak (Sunderland)	at 57 miles.
End of Light Streak (Sunderland)	at 45 miles.
End of Meteor (Bristol)	at 37 miles.
Inclination to Mean horizon	57 degrees.
Entire length of observed real path (Bristol)	34 miles.

The Meteor's Earth-point was situated in about Lat. N., 55·6°, Long. E., 3·3°, and its radiant at 149°, +25°. The duration of its flight was not estimated, so its velocity cannot be determined. At Bristol however it was described as 'swift,' and the inference is that its motion probably accorded with the usual high rate of speed attributed to the Leonid Meteors. The heights above stated do not differ materially from the average of fireballs, though the length of the path was decidedly shorter than usual[g].

[g] Denning, *Month. Not.*, vol. xlix. p. 66, Dec. 1888.

CHAPTER III.

SHOOTING STARS.

Have only recently attracted attention.—Are visible with greater or less frequency every clear night.—Summaries of the monthly and horary rates of apparition from observations by Coulvier-Gravier and Denning.—Number of known meteor showers.—Their distribution amongst the constellations.—Monthly number of meteors catalogued.—Early notices of great meteor showers.—The showers of 1799, 1831, 1832, 1833, 1866, *and following years.—The shower of Aug.* 10.—*Of Nov.* 27, 1872, *and Nov.* 27, 1885.—*Nomenclature of meteor systems.—Views of Olbers.—Monthly summary of great meteoric displays.*

SHOOTING stars, although noticed in ancient times, have attracted special attention only during the present century. This branch of the science may therefore be considered to be comparatively in its infancy. Though a vast number of observations have now been accumulated and are available for discussion we require many more, and a searching investigation of the whole subject, before we can claim to have thoroughly mastered its details and to have explained certain peculiarities which are not quite in harmony with prevailing theories. The labours of Heis and Schmidt, of A. S. Herschel and Greg, of Schiaparelli and many others, have however so far smoothed the way to a satisfactory conception of the movements and physical nature of these objects that much of the former mystery concerning them has been cleared away, and we have a substantial basis on which to augment our knowledge[a].

Shooting stars were long considered to have an atmospheric origin and to be due to the combustion of inflammable gases exhaled by the earth. This theory is now rejected in favour of one which is perfectly consistent with the observed features of these

[a] A pamphlet by T. Bredechin entitled *Sur l'origine des étoiles filantes,* published at Moscow, 1888, may be mentioned in this connection.

bodies. They are of celestial origin, pursuing orbits similar to comets, and grouped into streams containing in many cases an immense assemblage of particles. They become visible to us on being inflamed by friction with our atmosphere, into which they rush with planetary velocity and are instantly consumed and reduced to imperceptible dust.

There is no clear night throughout the year on which a certain number of shooting stars are not visible. When the air is transparent, the moon absent, and the stars shining brightly, about 8 or 10 may be noticed every hour. The horary average will be greater if the sky is watched in the morning hours during the last half of the year. At such times it is often possible to note 20 or 25 of these objects during an hour, though no particularly active shower may be in progress at the time. On certain specific nights the numbers visible exhibit a great increase, due to the recurrence of *periodic* showers. On ordinary nights the shooting stars which are seen belong to a number of feeble streams, and were formerly called *sporadic* meteors, but the term has now lost much of its significance, for it has been proved that as a rule the seemingly erratic members belong to definite systems whose radiant points are capable of being discovered by prolonged and critical observation. Certain of these systems appear to be of extreme tenuity, so that a single observer may only notice, during an entire night, one or two meteors from each of them. It is therefore found necessary to combine the records of several consecutive nights of observation in order to ascertain their radiant points.

There is a variation in the visible number of meteors, which is regulated both by the season of the year and the hour of the night. During the last six months of the year there are double the number compared with the first six months. As to the diurnal variation, it is found that the hourly rate increases up to 2 or 3 A.M., when the maximum is reached. From a large number of observations by M. Coulvier-Gravier the following numbers were derived [b]:—

[b] *Recherches sur les Météores et les lois qui les régissent,* Paris 1859, pp. 217–20.

h.		h.	Jan. to June.	July to Dec.	Whole year.
5	to	6 even.	8·5	7·0	7·2
6	,,	7 ,,	3·1	6·5	6·5
7	,,	8 ,,	3·4	8·5	7·0
8	,,	9 ,,	2·7	8·4	6·3
9	,,	10 ,,	3·2	11·0	7·9
10	,,	11 ,,	3·1	12·1	8·0
11	,,	12 midnight	4·1	13·3	9·5
12	,,	1 morn.	5·2	14·5	10·7
1	,,	2 ,,	6·6	17·0	13·1
2	,,	3 ,,	8·1	20·4	16·8
3	,,	4 ,,	6·7	18·7	15·6
4	,,	5 ,,	6·2	18 4	13·8
5	,,	6 ,,	6·8	18·4	13·7
6	,,	7 ,,	6·1	17·2	13·0

Below is added for comparison the horary number found from observations at Bristol. About three-fourths of these were however obtained during the last half of the year, and the figures (which show a good agreement with M. Coulvier-Gravier's) are therefore rather higher than would be yielded by data equally distributed over the first and last six months:—

h.		h.		h.		h.	
6	to	7 even.	8·0	12	to	1 morn.	12·9
7	,,	8	6·8	1	,,	2	15·3
8	,,	9	8·5	2	,,	3	15·3
9	,,	10	8·7	3	,,	4	15·0
10	,,	11	11·6	4	,,	5	16·3
11	,,	12 midnight	11·0	5	,,	6	14·5

As to the monthly mean of the hourly number of visible shooting stars, the following values are given by MM. Coulvier-Gravier and Saigey and by Denning:—

Month.	Coulvier-Gravier and Saigey.	Denning.	Month.	Coulvier-Gravier and Saigey.	Denning.
Jan.	3·6	8·0	July	7·0	12·0
Feb.	3·7	5·8	Aug.	8·5	12·9
Mar.	2·7	6·7	Sept.	6·8	10·9
April	3·7	7·0	Oct.	9·1	12·2
May	3·8	5·5	Nov.	9·5	10·9
June	3·2	5·0	Dec.	7·2	9·6
Jan. to June	3·4	6·3	July to Dec.	8·0	11·4

The two series of figures, though not agreeing amongst themselves, yet plainly indicate the great excess of shooting stars during the last half of the year. Aërolites and Fireballs, indeed every form of meteoric phenomena, appear to attain their maximum during the period from July to December. There is a great increase in the horary numbers at about the middle of July, and an equivalent decrease at the middle of December. Though the earth is much nearer to the sun during the last half of December and in January than in July and August, the rate of meteoric apparitions during the former period is scarcely more than one-third that of the latter. This circumstance is mentioned by way of challenge to the idea that meteors are more densely aggregated in regions nearer the sun. The systems of these bodies annually encountered by the Earth evidently manifest a peculiar distribution which further observations may elucidate.

Mr. Greg's last general catalogue[c] of the radiant points of shooting stars, published in 1876, was based on 850 radiants deduced from 15,000 catalogued meteors. At the present time we have more than 3000 radiants, derived from upwards of 82,000 meteors. These observations have been rapidly accumulating in recent years. Of the 3000 radiants referred to as having been now determined, a large proportion are duplicate positions of identical showers, and it is probable that not more than 500 distinct showers have been definitely ascertained.

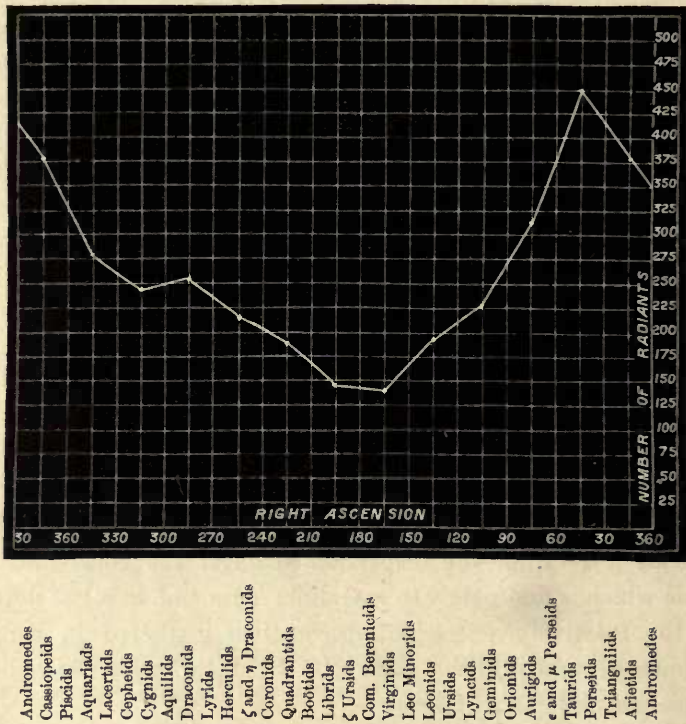
Upon analysing all the positions, Denning finds that they indicate a very uneven dispersion amongst the constellations, a fact which is due partly to real differences and, in a less degree, to the relatively excessive observations gathered in certain favourable months of the year. In Right Ascension the radiant points are situated as follows:—

R.A. °		°	Radiants.	Per cent.	R.A. °		°	Radiants.	Per cent.
1	to	30	378	12·4	181	to	210	147	4·8
31	,,	60	449	14·8	211	,,	240	186	6·1
61	,,	90	315	10·3	241	,,	270	217	7·2
91	,,	120	229	7·6	271	,,	300	254	8·4
121	,,	150	192	6·3	301	,,	330	243	8·0
151	,,	180	142	4·7	331	,,	0	283	9·3

[c] *Brit. Assoc. Rep.*, 1876, p. 119. These and the following notes with reference to the distribution of meteor showers are from the *Month. Not.*, vol. xlvii. pp. 35–39 (Nov. 1886).

The meteor streams are found in greatest abundance between 1° and 60° of R.A. This is a fact irrespective of the cometary showers of Andromedes (Nov. 27) and Perseids (Aug. 10), which fall in this region, and might be supposed to have induced the singular condensation referred to. The area, following it, from 61° to 90°, shows a great decline, notwithstanding it includes

Fig. 245.



DISTRIBUTION OF METEOR STREAMS IN RIGHT ASCENSION.

the Orionids (Oct. 17–20), and the mass of showers originating in *Auriga*, *Camelopardus*, and the eastern quarter of *Taurus*. And the area, 331° to 0° preceding the area of maximum, though rich in Aquariads, Pegasids, Lacertids, and Cepheids, exhibits a great deficiency as compared with it. The excess, so decided in character, between 1° and 60° is distinctly to be attributed to the Cassiopeïds, α, β, and γ Andromedes, Arietids, Muscids, α and β Perseids, Taurids, &c., which, combined with the cometary showers of Andromedes and Perseids, swell the aggregate number to an abnormal figure.

The minimum proportion of showers is clearly between 151° and 210° R.A., and does not much exceed one-third of those grouped between 1° and 60°, the relative figures being 289 and 827.

In North Polar Distance the showers are placed as follows:—

N.P.D. ° °	Radiants.	Per cent.	N.P.D. ° °	Radiants.	Per cent.
0 to 9	39	1·3	60 to 69	392	12·9
10 " 19	141	4·7	70 " 79	335	11·0
20 " 29	243	8·0	80 " 89	211	6·9
30 " 39	473	15·6	90 " 99	127	4·2
40 " 49	489	16·1	+99	170	5·6
50 " 59	415	13·7			

The maximum obviously lies between 30° and 49° N.P.D., and the minimum naturally occurs at the pole, inasmuch as the zone 0° to 9° includes a much smaller area than any other.

The distribution of the observed radiants in N.P.D. is affected by the differences in the areas of the several zones and their relative degrees of visibility. Though towards the pole the total space included in the zones becomes less, yet this is in a large measure compensated for by their more favourable position and the persistency with which they are displayed to view. The entire zones, from 0° to 49° N.P.D., never fall below the horizon in England, and such showers as they present are therefore determinable at any period of the year or time of night. This applies specially to English latitudes, but it also has a general reference (with perhaps slight modifications in certain instances) because nearly all our existing observations of shooting stars have been made at stations having considerable (*i.e.* exceeding 35°) North latitude. The summary proves that while the two zones embraced between the parallels of 30° and 49° N.P.D. have the largest number of recorded streams, the three zones succeeding towards the equator exhibit a gradual decline, though each remains fairly prolific. The Andromedes, Perseids, and Quadrantids are arranged between 30° and 49°, while the Geminids, Leonids, and Lyrids, lie between 50° and 69° N.P.D. Considering all the circumstances, there do not appear to be great inequalities of grouping in North Polar Distance analogous to those which undoubtedly occur in Right Ascension, but the point requires further investigation.

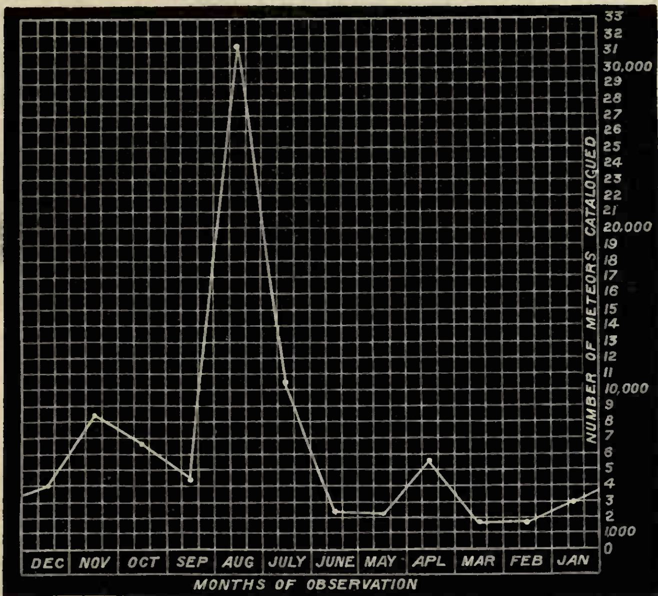
In considering the distribution of meteor streams, several important conditions must not be lost sight of. The bulk of the observations have been effected in the summer months, whence it necessarily follows that such constellations as are most favourably visible at this period must certainly appear to exhibit a predominance of showers. The comparative monthly numbers of meteors registered (82,156 meteors in all) yield the following result:—

Month.	Meteors Catalogued.	Per cent.	Month.	Meteors Catalogued.	Per cent.
January	2804	3·4	July	10670	12·1
February	1826	2·2	August	31516	38·1
March	1764	2·1	September	4304	5·1
April	5585	6·8	October	6840	8·3
May	2120	2·6	November	8319	11·3
June	2353	2·9	December	4055	4·9

These numbers are derived from the catalogues of Corder, Denning, Denza, Heis, Konkoly, Lucas, Sawyer, Schmidt, Tupman, Weiss, Zezioli, and the Italian Meteoric Association, 1869, 1870, and 1872, and some minor lists.

More than one-half the total number of observations were obtained in July and August, and, in point of fact, are nearly all embraced between the period from July 20 to August 15. The majority of the observations have been secured before midnight, and it is therefore certain that the region of 31° to 60° R.A., which is for the most part either below the horizon or low in the North-East at the special epoch when the largest number of meteors have been recorded, is not rendered rich solely by this abundance of observations. Indeed the months of September, October, and November appear to have furnished, relatively to the number of meteors catalogued, by far the greatest number of showers in this quarter of the sky. It seems, therefore, that the great fertility in streams of the region about *Andromeda. Aries*, and *Perseus* is a real fact, which cannot be explained away on the

Fig. 246.



RELATIVE NUMBER OF METEORS CATALOGUED DURING THE SEVERAL MONTHS OF THE YEAR.

ground that it arises from excessive observations at special periods, or that it is due to any conditions likely to induce a misleading result.

I will now refer to the well-known and beautiful showers[d] of shooting stars seen at certain epochs with such striking effect.

One of the earliest notices we find in history of this phenomenon is by Theophanes the Byzantine historian, who relates that in November 472 A.D. the sky at Constantinople appeared to be on fire with flying meteors. Condé, in his history of the dominion of the Arabs, speaking of the year 902 A.D., states that in the month of October, on the night of the death of King Ibrahim-Ben-Ahmed, an immense number of falling stars were

[d] An interesting catalogue by Newton will be found in *Silliman's Journal*, 2nd Ser., vol. xxxvi. p. 145, July 1863: vol. xxxvii. p. 377, vol. xxxviii. p. 53, May and July 1864.

seen to spread themselves over the face of the sky like rain, and that the year in question was thenceforth called the "Year of Stars." In some Eastern Annals of Cairo it is related that: "In this year, in the month *Redjeb* [August 1029], many stars passed, with a great noise, and brilliant light;" and in another passage it says: "In the year 599, on Saturday night, in the last *Moharrun* [Oct. 19, 1202], the stars appeared like waves upon the sky, towards the east and west; they flew about like grasshoppers, and were dispersed from left to right; this lasted till daybreak: the people were alarmed." It is also recorded that a remarkable display took place in England and France on April 4, 1095. The stars seemed "falling like a shower of rain from heaven upon the Earth," and an eyewitness, having noticed where an aërolite fell, "cast water upon it, which was raised in steam with a great noise of boiling." In the Chronicle of Rheims we read that the stars in heaven were driven like dust before the wind, and Rastel says that: "By the report of the common people in this kynge's time [William II] divers great wonders were sene: and therefore the kynge was told by divers of his familiars that God was not content with his lyvying; but he was so wilful and proud of mind, that he regarded little their saying."

In modern times, the earliest shower of falling stars of which we have any detailed description is that of Nov. 13, 1799, which was visible throughout nearly the whole of North and South America: it was seen even in Greenland by the Moravian missionaries. Humboldt, then travelling with M. Bonpland, in South America, says:—

"Towards the morning [of the 12th] the most extraordinary luminous meteors were seen towards the E. . . Thousands of bolides and falling stars succeeded each other during 4 hours. Their direction was very regularly from North to South. . . . From the beginning of the phenomenon there was not a space in the firmament equal in extent to 3 diameters of the Moon that was not filled every instant with bolides and falling stars. . . . All these meteors left luminous traces from 5 to 10 degrees in length, as often happens in the equinoctial regions. The phosphorescence of these traces lasted 7 or 8 seconds [e]."

[e] Humboldt and Bonpland, *Personal Narrative of Travels*, trans. Williams, vol. iii. p. 331. Lond. 1881.

Mr. Ellicott, an agent of the United States, at sea in the Gulf of Mexico, thus describes the scene:—

"About 3 o'clock A.M. I was called up to see the shooting stars, as it is commonly called. The phenomenon was grand and awful; the whole heaven appeared as if illuminated with sky-rockets, which disappeared only by the light of the Sun after daybreak. The meteors, which at any one instant of time appeared as numerous as the stars, flew in all possible directions, except from the Earth, toward which they all inclined more or less; and some of them descended perpendicularly over the vessel we were in, so that I was in constant expectation of their falling among us[f]."

The same observer also states that his thermometer suddenly fell 30°, and the wind changed from S. to N.W., whence it blew with great violence[g] for 3 days.

Meteoric showers were also witnessed in North America, in the years 1814, 1818, and 1819.

Fine meteoric displays took place in 1831 and 1832, in both cases on Nov. 13. Captain Hammond, of the ship *Restitution*, then in the Red Sea, off Mocha, thus describes the latter:—

"From 1 o'clock A.M. till after daylight, there was a very unusual phenomenon in the heavens. It appeared like meteors bursting in every direction. The sky at the time was clear, the stars and Moon bright, with streaks of light and thin white clouds interspersed in the sky. On landing in the morning, I inquired of the Arabs if they had noticed the above. They said they had been observing it most of the night. I asked if ever the like had appeared before. The oldest of them replied that it had not[h]."

This shower was seen from Arabia, westward to the Atlantic, and from the Mauritius to Switzerland. Various descriptions of it and of other star showers were collected by Arago in a Memoir on shooting stars which will be alluded to again presently.

By far the most splendid display of shooting meteors on record was that of Nov. 13, 1833, and one which served to point out the periodicity of the phenomenon. It seems to have been visible over nearly the whole of the Northern portion of the American continent, or, more exactly, from the Canadian lakes nearly to the equator. Over this immense area a sight of the most imposing grandeur seems to have presented itself. The phenomenon commenced at about midnight, and was at its height at about

[f] *Trans. of the American Philosophical Soc.*, vol. vi. p. 28. 1809.

[g] The prevalence of meteors was formerly considered an unfailing indication that windy and stormy weather was likely to occur.

[h] *Silliman's American Journ.*, 1st Ser., vol. xxvi. p. 136. 1834.

5 A.M. Several of the meteors were of peculiar form and considerable magnitude. One was especially remarked from its remaining for some time in the zenith over the Falls of Niagara, emitting radiant streams of light. In many parts of the country the population were terror-stricken by the beauty and magnificence of the spectacle before them. A planter of South Carolina thus narrates the effect of the phenomenon on the minds of the ignorant blacks:—

"I was suddenly awakened by the most distressing cries that ever fell on my ears. Shrieks of horror and cries for mercy I could hear from most of the negroes of the 3 plantations, amounting in all to about 600 or 800. While earnestly listening for the cause I heard a faint voice near the door, calling my name. I arose, and, taking my sword, stood at the door. At this moment I heard the same voice still beseeching me to rise, and saying, 'O my God, the world is on fire!' I then opened the door, and it is difficult to say which excited me the most—the awfulness of the scene, or the distressed cries of the negroes. Upwards of 100 lay prostrate on the ground—some speechless, and some with the bitterest cries, but with their hands raised, imploring God to save the world and them. The scene was truly awful; for never did rain fall much thicker than the meteors fell towards the Earth; east, west, north, and south, it was the same [i]."

The meteors of which the above shower was composed seem to have been seen of 3 different kinds:—

1. Phosphoric lines, apparently described by a point. These were the most abundant; they passed along the sky with immense velocity, as numerous as the flakes of a sharp snow-storm.

2. Large fireballs, which darted forth at intervals across the sky, describing large arcs in a few seconds. Luminous trains marked their paths, which remained in view for a number of minutes, and in some cases for half an hour or more. The trains were generally white, but the various prismatic colours occasionally appeared, vividly and beautifully displayed. Some of these fireballs were of enormous size; indeed, one was seen larger than the Moon when at its full.

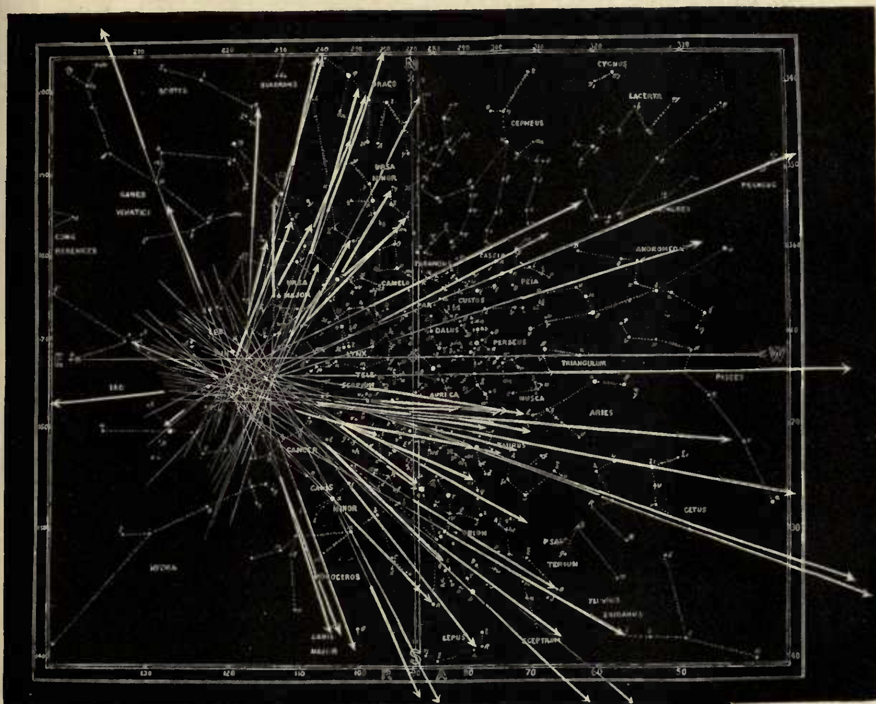
3. Luminosities of irregular form, which remained stationary for a considerable time. The one above mentioned as having been seen at the Falls of Niagara was of this kind [k].

[i] Quoted in Milner's *Gallery of Nature*, p. 140.

[k] Quoted in Milner's *Gallery of Nature*, p. 141 (abridged).

Subsequently to 1833 the month of November was for some years distinguished by an unusual number of shooting stars; but none of the showers equalled that which I have just described, though those of 1866 and 1867 were extremely striking, the former one, perhaps, especially so.

Fig. 247.



THE METEOR RADIANT POINT IN LEO:
TRACKS OF METEORS SEEN AT GREENWICH, NOV. 13, 1866.

The following letter, penned by Dawes, who observed the meteors in Buckinghamshire, furnishes us with a brief and clear description of most of the salient features of the shower of 1866, which were attentively watched and very similarly described by other competent observers:—

"Between midnight on the 13th and $14^h\ 13^m\ 10^s$ (G.M.T.) 2800 meteors were counted by myself and one assistant in the eastern hemisphere. Another assistant looking out to the West counted nearly 400 in an hour, but became so bewildered by 6 or 7 bursting out almost simultaneously, and this repeatedly, that the attempt to count more was given up. I have no doubt from what I saw myself in the western hemisphere, there must have been at least 700 visible in the 2¼ hours. Adding to these 75 which were seen before midnight, and we have upwards of 3500 in all, up to about a quarter past 2 in the morning.

"Some were brighter than Venus ever is; but none were at all comparable to several which appeared in 1832, Nov. 12, of which, however, I have never met with any good or particular account [l]."

Most of the reports of experienced observers who watched the progress of the shower continuously, concur in placing at about 3000 or 4000 the total number that they saw, and which they could have counted; though it should be stated that the staff of the Greenwich Observatory, as the result of a cleverly pre-arranged subdivision of work, were able to count more than 8000.

The shower was at its height in England from about $12^h\ 45^m$ to $1^h\ 45^m$ A.M., when the radiant point in Leo had risen about 25° above the Eastern horizon. The position of this radiant was in R.A. 149°, Decl. + 23, corresponding very nearly with the place given by Prof. Aiken for the shower of 1833 at R.A. 148°, Decl. + 24°. Before 4 A.M. the shower had almost ceased. Its display was vertical over a meridian about 75° E. of Greenwich, and it was accordingly confined to the Old World and quite invisible in America. In 1867, 1868, and 1869 the shower recurred on the same date, though declining each year, and was brilliantly visible in America, though not comparable with the display of 1833. Since 1872 this phenomenon has been feebly visible at its annual returns, though re-observed at Bristol in 1876, 1877, 1879, 1885, 1887, and 1888. In 1879 and 1888, on the morning of Nov. 14, the shower was rather conspicuous, and it furnished some brilliant meteors from the same radiant as observed in 1833 and 1866.

Another meteor shower of great importance occurs annually on Aug. 10. Public attention was first directed to that date by Ignace Marie Thomas Forster, of Bruges [m], and his diary even contained a note of its annual character as early as the year 1811. But it

[l] *Ast. Reg.*, vol. iv. p. 306. Dec. 1866. In *Ast. Reg.*, vol. xiii. p. 271, Nov. 1875, Mr. Webb drew attention to Dawes's original observations of the meteors of Nov. 12, 1832, in the *Mem.*, R. A. S., vol. viii. p. 76. (Notes to a Star Catalogue.)

[m] *The Perennial Calendar*, p. 400, Lond. 1824.

was not until A. Quetelet constructed in 1836 the first general catalogue of meteor showers, that the fact of its annual recurrence was fully recognised and established. The shower was independently expected and successfully observed by E. C. Herrick in the United States[n], and by Quetelet at Brussels, in the years 1836 and 1837; and it has since never failed to be annually recorded. Years of maximum and minimum brightness have occasionally been noticed, the year 1863 having been of the former, and the years 1862, 1876, and 1888 of the latter class, but meteors of this shower appear never to be entirely absent during the nights of August 9–11 in each year. Herrick regarded the position of the radiant-point as being near the cluster (χ) in the sword-hand of Perseus; and another position at B, C, Camelopardi was also noted by Sir John Herschel at Slough in the year 1840. The exact radiant point has more recently been determined with great precision at R.A. 45°, Decl. + 57°, which is a few degrees N.E. of the star η Persei. This stream is remarkable for its extended duration, and for the obvious displacement which occurs from night to night in the apparent position of its radiant. The period of its visibility appears to cover the 43 nights from July 11 to Aug. 22 inclusive, during which the centre of radiation advances from R.A. 11°, Decl. + 48°, to R.A. 76°, Decl. + 57°, according to the observations of Denning. The following are the places successively taken up by the radiant on different nights:—

Date.	R.A. °	Decl. °	Date.	R.A. °	Decl. °
July 11	11	+ 48	Aug. 10	46	+ 57
„ 18	18	+ 51	„ 15	54	+ 57
„ 25	27	+ 53	„ 19	67	+ 57
Aug. 1	35	+ 55	„ 22	76	+ 57

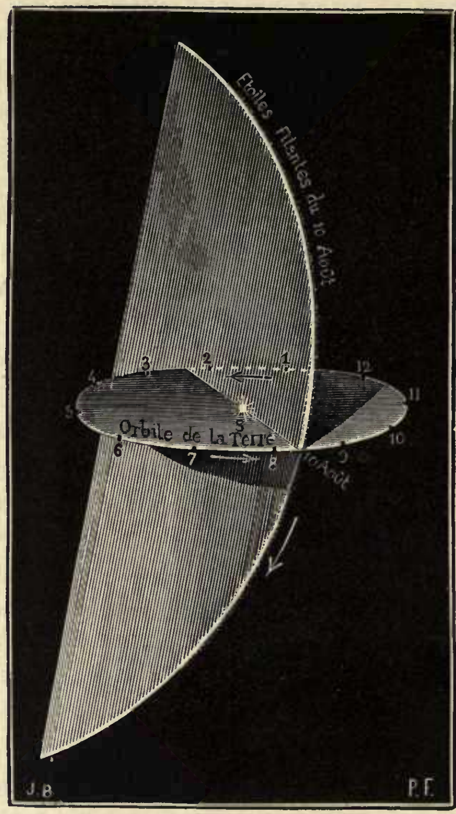
The displacement in the radiant[o] is more rapid after the maximum on Aug. 10 than before it. This shower does not exhibit great variations in its annual richness; on the morning of Aug. 11 it usually yields from 60 to 80 meteors per hour for one observer.

[n] *Silliman's Journal,* 1st Ser., vol. xxxiii. pp. 176 and 354.

[o] A displacement is also suspected in the diverging point of the April meteors and some other showers. In 1888 the earliest indication of the Perseid shower was seen on July 8 with radiant at R.A. 3°, Decl. + 49°, (see p. 641).

Fig. 248 will convey a general idea as to the position of the plane of the orbit of the shooting stars of August 10 relatively to the plane of the orbit along which the earth travels round the sun. It will also illustrate the annual encounter of the earth on the day in question with these meteors, in numbers few or great,

Fig. 248.



INTERSECTION OF THE PLANE OF THE ORBIT OF THE EARTH BY THE SHOOTING STARS OF AUGUST 10.

according to the circumstances of each year. The figures from 1 to 12 represent the 12 months of the year.

Another meteor shower has in recent years become very prominent. It occurred with imposing grandeur on November 27, 1872, and November 27, 1885, and was widely observed. The abundance of its meteors was remarkable on both occasions. Mr. E. J. Lowe, who watched the display of 1872, computed that 58,660 meteors fell during the period from 5^h 50^m to 10^h 30^m P.M. At Moncalieri, 33,000 meteors were counted by Denza and his assistants. Prof. Herschel collected and compared the positions of the radiant as given by 90 observers. He found the mean place at R.A. 25·1°, Decl. + 42·9° (closely N.W. of γ Andromedæ), from 35 of the best observations. This shower recurred with equal splendour on Nov. 27, 1885. At Moncalieri, Denza and 3 assistants observed nearly 40,000 meteors during the 4^h from 6 to 10 P.M. At many other stations, both in England and abroad, the phenomenon was of similar intensity, and it was watched with all the ardour that a great celestial event can inspire. It was particularly noticed that the radiation was diffused over 7° or more near the star γ Andromedæ, and Ranyard considered it to have been elliptical, with its major axis North and South, 12° or 15° long, and a minor axis of 6° or 8°. Denning found the mean position of the radiant from 33 observations to be at R.A. 23·7°, Decl. + 44.3°, which accords closely with the centre assigned by Prof. Herschel for the shower of 1872.

These meteors are called *Andromedes*, from the fact that they diverge from Andromeda. The shower of Nov. 14 is termed the *Leonids*, and that of August 10 the *Perseids*. Some other conspicuous showers are distinguished by titles: thus we have the *Quadrantids* of Jan. 2, the *Lyrids* of April 20, the *Orionids* of Oct. 18–20, and the *Geminids* of Dec. 10–12, &c.

The annual recurrence of the January shower was noticed by Wartmann at Geneva in 1835–8, and its radiant-point was determined by Stillman Masters in America in January 1863. The recurrence of the April and October showers was shown by Herrick, in America, in 1839, who also ascertained their radiant-points. The November shower of *Andromedes* has appeared at intervals since the close of the last century, and we owe to Herrick in 1838, and subsequently to Heis and Schiaparelli, the best observations of its radiant-point previously to one of its cyclical returns in the year 1872. Like all the foregoing meteor showers, except the last, the *Geminids* are also *annually* recurrent, and this character was noticed and the radiant-point of the shower was determined simultaneously by Mr. Greg in England, and by Professor Twining in America, on December 12, 1863. Indications of periodicity and of early notices of years of maxima in these appearances have been sought for, with some success, in catalogues of meteor showers by Prof. Newton [p] and Prof. Kirkwood with the probable result announced by Kirkwood [q] that the meteors of April, October, and December revolve in periods respectively of 28½, 27½, and 29 years, while the January meteor ring has a suspected period of about 13 years.

Many of the astronomical views concerning shooting stars adopted before the first predicted return of the November meteors in 1866–67 were due to a valuable memoir by Olbers [r], in which in the place of orbits approximately circular like those conceived by Biot, and in the contemporaneous paper on shooting stars above referred to, by Arago, they were assumed to move rather in comet-like or very elongated orbits. The 33-year cycle of the November meteors was pointed out and thus explained by Olbers, who also ventured to predict a probable great return of the November meteors about the year 1867, which prediction, as well as the grounds upon which it rested, was verified by the event.

Subdividing the recorded instances of great showers of shooting stars according to the months of the year, we obtain the following results :—

January	10		July	14	
February	10		August	56	
March	12	55	September...	13	167.
April	17		October	29	
May	4		November...	38	
June	2		December	17	

We thus find, and it is worthy of especial remark, that the coincidence to which I have already adverted in the case of aëro-

[p] *Silliman's Journal*, 2nd Ser., vol. xxxvi. p. 145, July 1863.

[q] *Proceedings of the American Philosophical Society*, vol. xi. p. 299, March 4, 1870, and vol. xiii. p. 501, Nov. 21, 1873.

[r] Schumacher's *Jahrbuch*, 1837, p. 36.

lites, fireballs and other meteors also obtains with the showers of shooting stars—namely, that the Earth encounters a larger number of these bodies in passing from aphelion to perihelion, or between July and January, than in passing from perihelion to aphelion, or between January and July.

In concluding this chapter, brief reference may be made to the apparent magnitudes of meteors [s]. From many thousands of observations recorded in various published catalogues it would appear that the following is something like the relative brightness of these bodies :—

	Star of— > 1st mag.	= 1st.	= 2nd.	= 3rd.	4th mag. and less.	Total No. of Meteors.
Per cent.	3·0	10·6	18·4	26·2	41·8	35·134
Increase per cent. ...		7·6	7·8	7·8	15·6	

The numbers show a definite increase of 7·8 per cent. There is an enormous excess of faint meteors as compared with the more brilliant forms of these phenomena [t].

[s] An article in *The Observatory*, vol. ii. p. 20 (May 1878), may be consulted for further details.

[t] A catalogue of 221 meteoric showers is given in Arago's *Ast. Pop.*, vol. iv. pp. 292–314. Also a catalogue, extending from 538–1223 A.D., by Chasles, in *Compt. Rend.*, vol. i. pp. 499–509. 1841. For an account of Quetelet's Catalogue see p. 628, *post*.

CHAPTER IV.

THE THEORY OF METEORS.

Meteors are planetary bodies.—Their periodicity.—Meteoric orbits.—Researches of Newton and Adams.—Orbit of the meteors of November 13.—Identity of the orbits of comets and meteors.—The meteor showers of Nov. 13 and 27.—Recent progress of Meteoric Astronomy.—Table of the chief radiant points.

IT has been mentioned in a previous chapter that it is to some extent doubtful whether aërolites, fireballs and shooting stars are manifestations of identical phenomena or whether they belong to distinct classes of bodies. There is much evidence to warrant the assumption of identity, and it will be convenient to adopt this view during our further consideration of the subject.

Many theories have been propounded to explain luminous meteors, but they were usually based on few observations, and later researches did not support them. But in recent years a theory has been framed which so well accords with observed facts that it has received universal recognition.

Meteors are diminutive planetary bodies revolving round the sun in orbits similar to those pursued by comets. These orbits intersect the annual path of the Earth, and hence it follows that whenever the Earth passes through these points of intersection there is a *rencontre* with the meteoric particles, which are thereupon propelled into our atmosphere with great velocity and are ignited by the friction generated by the force of impact. Fireballs of ordinary noiseless character and shooting stars are entirely consumed and dissipated before reaching the lower regions of the atmosphere, while aërolites are meteors which succeed in penetrating completely through the air strata and ultimately fall upon the Earth's surface.

With the meteors there prevails, as we have already seen, a periodicity: this will be found on examination to countenance the theory of their being planetary in their nature; and the well-known experiment of igniting tinder by compressing air in a fire syringe removes the notion of self-ignition from the domain of fanciful speculation.

With reference to their periodicity, Sir J. Herschel says[a]:—

"It is impossible to attribute such a recurrence of identical dates of very remarkable phenomena to accident. Annual periodicity, irrespective of geographical position, refers us at once to the place occupied by the Earth in its annual orbit, and leads directly to the conclusion that at that place it incurs a liability to *frequent* encounters or concurrences with a stream of meteors in their progress of circulation around the Sun. Let us test this idea, by pursuing it into some of its consequences. In the first place, then, supposing the Earth to plunge in its yearly circuit into a uniform ring of innumerable small meteoric planets, of such breadth as would be traversed by it in one or two days; since, during this small time, the motions, whether of the Earth or of each individual meteor, may be taken as uniform and rectilinear, and those of all the latter (at the place and time) parallel, or very nearly so, it will follow that the relative motion of the meteors, referred to the Earth as at rest, will be also uniform, rectilinear, and *parallel.* Viewed, therefore, from the centre of the Earth (or from any point of the circumference, if we neglect the diurnal velocity, as very small compared with the annual), they will all appear to diverge from a common point, *fixed in relation to the celestial sphere*, as if emanating from a sidereal apex.

"Now this is precisely what happens. The meteors of the 12th–14th of Nov., or at least the vast majority of them, describe apparently arcs of great circles, passing through or near γ Leonis. No matter what the situation of that star, with respect to the horizon or to its East and West points, may be at the time of observation, the paths of the meteors all appear to diverge from that star. On the 9th–11th of August, the geometrical fact is the

[a] *Outlines of Astronomy*, 11th Ed., p. 661.

same, the apex only differing; B Camelopardi being for that epoch the point of divergence. As we need not suppose the meteoric ring coincident in its plane with the ecliptic, and as for a *ring* of meteors we may substitute an elliptic annulus of any reasonable eccentricity, so that both the velocity and direction of each meteor may differ to any extent from the Earth's, there is nothing in the great and obvious difference *in latitude* of these apices at all militating against the conclusion.

"If the meteors be uniformly distributed in such a ring or elliptic annulus, the Earth's encounter with them in every revolution will be certain, if it occur once. But if the ring be broken —if it be a succession of groups revolving in an ellipse in a period *not* identical with that of the Earth, years may pass without a *rencontre;* and when such happen, they may differ to any extent in their intensity of character, according as richer or poorer groups have been encountered."

We will now consider the character of meteor orbits, and in order to form a clear conception of the matter it may be necessary to go back a few years and trace the developments leading up to the present theory.

In November, 1833, there was witnessed, as has already been stated, a grand display of meteors[b] ("shooting stars"), a less grand one in 1832, and 33 years before that, namely in 1799, another very magnificent one. Availing himself of a comprehensive catalogue of recorded appearances of meteor showers compiled by A. Quetelet in 1836–39[c], a learned American astronomer, Prof. H. A. Newton, set himself the task[d] of searching out all the ancient records he could find of such displays: he found that more than a dozen had been taken note of by historians, beginning with 902 A.D., and that in all cases the intervals were either $\pm \frac{1}{3}$rd

[b] In this chapter the word "meteors" is intended to apply generally, to aërolites, fireballs, and shooting stars; in fact to all the allied, and probably identical, forms of meteoric apparitions.

[c] *Nouveaux Mémoires de l'Académie Royale des Sciences*, vol. xii. 1839.

[d] His papers appear in *Silliman's Journal*, 2nd Ser., vol. xxxvii. p. 377, and vol. xxxviii. p. 53, May and July 1864. The periodic dates of the November and of some other annual meteor showers had been discussed in a previous paper in the same *Journal*, vol. xxxvi. p. 145, July 1863.

of a century or some multiple of that period. This was too important a fact to be neglected. By a course of reasoning, the several steps of which I do not deem it necessary to reproduce, Newton concluded that the ±33-year visible periodicity was only reconcileable with an orbit whose period was either 180^d, $185{\cdot}4^d$, $354{\cdot}6^d$, $376{\cdot}6^d$, or $33{\cdot}25^y$. Why the true period must be one of these 5 involves mathematical considerations unsuitable to these pages. The period chosen by Newton himself as the most probable was that of $354{\cdot}6^d$, corresponding to an orbit nearly circular; but he pointed out that a certain retardation of the date which had taken place could only be explained by assigning to the meteor orbit that one of the 5 possible forms which would account for the retardation, and that a proper mathematical calculation undertaken for this purpose would finally decide which of the five forms was the real one. With these remarks on the orbit, and with a prediction that another great display would occur on the morning of November 14, 1866, Newton terminated his investigations.

In April, 1867, Prof. Adams presented to the Royal Astronomical Society an outline of a very important investigation [e] which, proceeding on Professor Newton's suggestion, he had brought to a satisfactory conclusion. Availing himself of Newton's labours, he sought to arrive at some more precise knowledge of the orbit of the November meteors, taking advantage, of course, of the information furnished by the observations made in November 1866. I should premise that Newton's inquiries show that the display which in 1866 happened on Nov. 13, in 902 happened on Oct. 12 (O. S.), indicating a progressive increase in the longitude of the points of intersection of the orbits of the meteors and the Earth. The amount of this motion is 102·6″ annually with respect to the Equinox or of 52·6″ with respect to the stars, equal to 29′ in 33¼ years. Adams calculated the extent of the progressive increase due to the perturbing influence of the planets Venus, Jupiter, and the Earth. He found that their conjoint effect, on the assumption that the

[e] *Month. Not.*, vol. xxvii. p. 247. April 1867.

period of the meteors was 180^d or 185^d or 354^d or 377^d, in no case exceeded 12′ in 33¼ years, but that assuming 33¼ years to be the period, planetary influence (in this case caused by Jupiter, Saturn, and Uranus) would produce an increase of 28′. The near coincidence of this theoretical 28′ with the observed 29′ places it almost beyond doubt that the true period is 33¼ years. Proceeding on this assumption, and having found that, according to the mean of several determinations, the radiant-point of the 1866 meteors was situated in:—

R.A. h. m.	Decl.
9 56	+23 1

Adams proceeded to calculate elliptic elements of the orbit of the meteors, and obtained the following set:—

Period	=	33·25^y (assumed)
Mean distance	=	10·3402
Eccentricity	=	0·9047
Perihelion distance	=	0·9855
Inclination	=	16° 46′
Longitude of Node	=	51 28
Distance of Perihelion from Node	=	6 51
Heliocentric motion		Retrograde.

Prof. Schiaparelli of Milan was also led at about the same time to investigate the phenomena of meteors [f]. He observed the *Perseids* on August 9, 10 and 11, 1866, and assumed, from the necessity of the conditions, that the orbit of these meteors must be an elongated conic section, and employing the method of Erman he computed parabolic elements for this system. It was not long afterwards that he discovered a remarkable resemblance between the meteoric orbit and the orbit of Comet iii. 1862, the two sets of elements being as follow:—

	August Meteors.	Comet iii. 1862.
Perihelion Passage	1862, July 23	1862, August 22·9.
Long. of Perihelion	343° 28′	344° 41′
Ascending node	138 16	137 27
Inclination	64 3	66 25
Perihelion Distance	0·9643	0·9626
Period	105 years?	123·4 years
Motion...	Retrograde... ...	Retrograde.

[f] *Month. Not.*, vol. xxxii. pp. 194–9. February 1872.

The periods are doubtful. The generally close agreement in the elements could only signify identity of the two orbits and of the bodies describing them. And a similar coincidence was found between the orbit of the November meteors (*Leonids*) and that of Comet i. 1866. The shower of April 20 (*Lyrids*) was also shown by Galle and Weiss to match Comet i. 1861, while the display of Nov. 27 (Andromedes) presented an equally close accordance with the well-known periodical comet of Biela.

The expected return of Biela's comet in August and September, 1872, afforded an opportunity for verifying the presumed connection; and the appearance of an abundant star-shower agreeing identically in the position of its radiant-point and in the date of its appearance with those of a meteor-stream following directly in the track of Biela's comet (about 12 weeks after the comet's departure from the place), on November 27, 1872[g], corroborated afresh an inference already drawn from the three previously known examples of agreement, that a very rich assemblage of the meteors revolving with a cometary body *follows* the comet very closely in its orbit[h]. A somewhat different surmise from this conjecture is however suggested by the showers of Andromedes seen in the years 1798, 1830, and 1838, which must have *preceded* Biela's comet at different distances between $\frac{1}{20}$ and $\frac{1}{3}$ of a revolution along its track. A separate group of the Leonids is also suspected to exist, preceding the principal one about 12 years (or about $\frac{1}{3}$ of a revolution) in its appearance. Notable star showers are recorded to have taken place in 855–56, 1787, and 1818–23, and finally by Prof. D. Kirkwood in 1852, agreeing exactly with the principal cluster in the day, and very closely also in the period of their returns[i]. The original dismemberment of the comet, to which the ancient

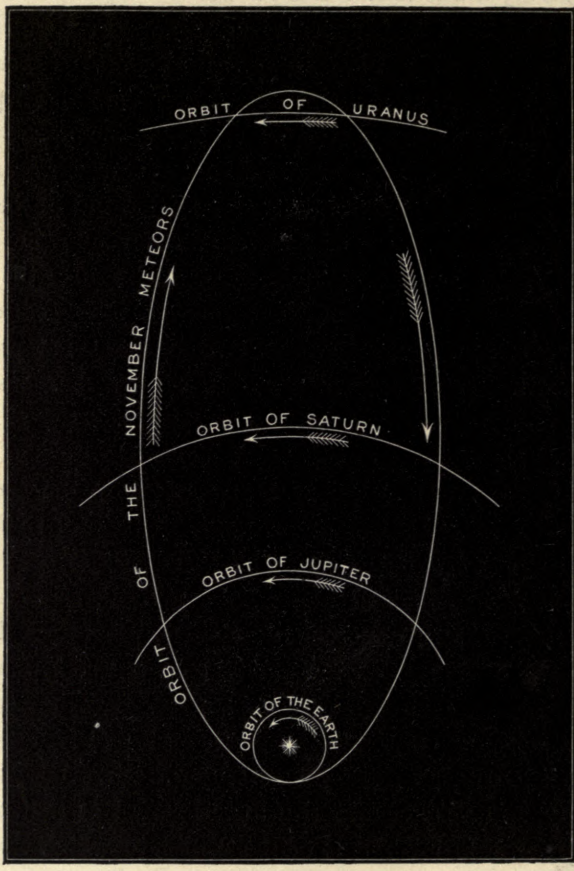
[g] This display recurred with great brilliancy on Nov. 27, 1885, after the completion of two revolutions, of 6·5 years each, of the derivative comet.

[h] It seems to be often overlooked, or not generally known, that the cometary character of the November shower of Meteors was first suggested by Denison Olmsted as far back as 1834. (*Silliman's Amer. Journ.*, vol. xxvi. p. 172.) The period he assigned was 182^d, which is in close agreement with one of the possible periods assigned by H. A. Newton many years later.

[i] *Nature*, vol. xi. p. 407, March 25, 1875; vol. xii. p. 85, June 3, 1875.

record of this widely distant cluster points, must have been of extraordinary antiquity, since the interval of 12 years between the years 855–56 and the next principal Leonid display in 868 differs very much from the distance still found to separate

Fig. 249.

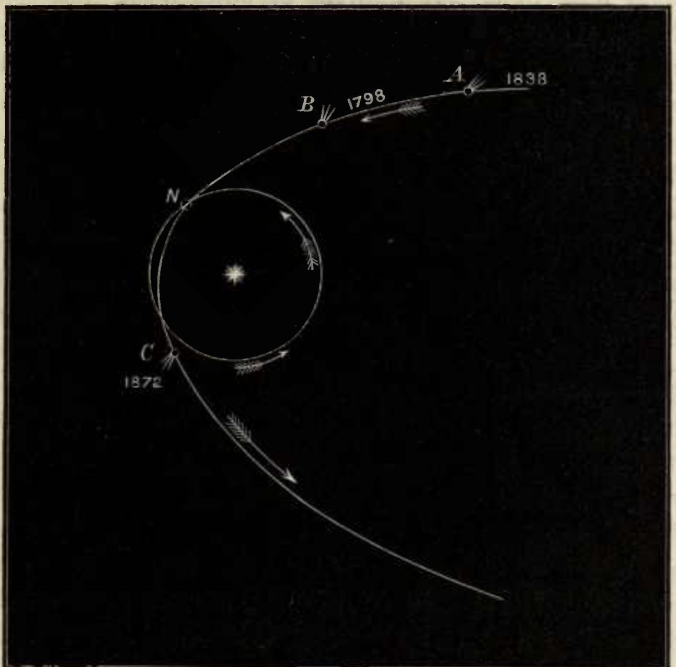


ORBIT OF THE LEONIDS OF NOV. 13 RELATIVELY TO THE ORBITS OF CERTAIN PLANETS.

the two clusters from the well-marked minor apparitions of the years 1787, 1820, and 1822 compared with the modern appearances of the chief cluster in 1799 and 1833. 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.

The orbit of Comet i. 1866, discovered by Tempel on Dec. 19, 1865, coincides with the *Leonid* meteor orbit given in Fig. 249.

Fig. 250.



POSITIONS OF BIELA'S COMET AT THE TIME OF THE METEOR SHOWERS OF 1798, 1838, AND 1872.

Prof. Newton, in a lecture delivered in 1874 at Yale College, indicated the positions of Biela's comet in its orbit relatively to the Earth at the times of occurrences of the greatest meteor-showers known to have arisen from the Earth's approach to this comet's orbit. The line of the nodes, or the place of the earth's nearest approach to the comet's track, being at N., it appears that in the year 1798, at the time when the Earth encountered at that point the great meteor shower of Dec. 6 of that year, observed by Brandes, Biela's comet was in the position marked B, somewhat nearer to the earth than on the next occasion when a similar display was witnessed in 1838. The comet was in the latter year at the point marked A about 300 millions of miles distant along its orbit from the earth. At the recurrence of this great star shower on Nov. 27, 1872, the comet must have been situated near C, or 200 millions of miles along the comet's path from the node N. From this it appears that the meteoric particles must be thickly distributed over at least 500 millions of miles of the comet's orbit, preceding the comet 300 millions and following it 200 millions of miles.

There is little doubt remaining that comets furnish the numerous meteors which traverse the celestial spaces. The fact of the intimate association of these phenomena is proved by the identity of their orbits, and by other evidence gleaned from observation which amply supports the views of Schiaparelli. To him must be given the credit of first demonstrating the connection, though the meritorious labours of several other astronomers cleared the way and furnished many of the materials the utilisation of which led to the actual discovery. Thus, several years before Schiaparelli commenced his researches, Professor Kirkwood broached the theory that "meteors and meteoric rings are the *débris* of ancient but now disintegrated comets whose matter has become distributed around their orbits[k]." Earlier writers had also expressed ideas which do not differ essentially from those now adopted, but unfortunately they could not command the data required to give practical support to their views, which were, in consequence, disregarded, as mere speculations.

The two great meteor showers of November are more certain in their cometary relations than the showers of April and August, because in the former instances the periodical maximum returns of the meteors have occurred at the predicted times and the time of revolution of both comets and meteors are precisely the

[k] *Danville Quarterly Review,* December 1861.

same. But in the case of the April and August systems the periods are open to considerable uncertainty, the orbits being of far greater excentricity.

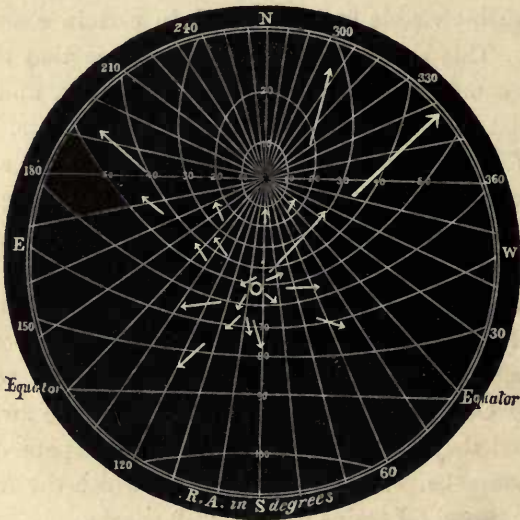
The meteors of November 13 may be expected to reappear with great brilliancy in 1899, and probably, for a year or two both before and after that date, a large number of these bodies will be seen at the middle of November. Possibly also there will be fine showers from Biela's comet on Nov. 26 or 27, in 1892 and 1898.

It is a noteworthy fact that the members of different meteor showers exhibit visible features which in certain cases are quite dissimilar. This arises from the circumstance that the various showers encounter the earth at different angles, and their apparent speed depends in a great measure upon this. Thus the meteors of November 13 (*Leonids*) are moving in a direction opposite to the Earth; hence their velocity is very great, being about 44 miles per second. But the meteors of Nov. 27 (*Andromedes*) are moving in nearly the same direction as the Earth, and hence have to overtake us, so that they apparently move very slowly, their speed being only 11 miles per second. The Leonids above referred to, together with the Perseids of Aug. 10 and the Orionids of Oct. 18–20, are good examples of the swift-moving meteors, and they are almost invariably accompanied by phosphorescent streaks. The slow meteors, of which the Andromedes are a type, throw off trains of yellowish sparks.

Since the astronomical nature of meteors has been admitted a large amount of attention has been given to this branch of the science. A committee of the British Association was for many years engaged in collecting and collating observations. Amongst those who have exerted themselves to develope this branch of astronomy must be mentioned the names of Adams, Challis, Denning, Glaisher, Grant, Greg, A. S. Herschel, Lowe, Main, and Tupman, in England; and among the chief astronomers abroad, who are either seeking or who have contributed to promote its progress, Twining and Newton, Loomis, Kirkwood, B. V. Marsh, Le Verrier, E. Quetelet, Buchner, Von Boguslawski, Galle, Heis, Neumayer, Schmidt, Weiss, Wolf, Schiaparelli, Denza, Secchi, Serpieri, and Tacchini, with other observers, especially in Italy, who watch nightly for shooting stars, and carry out with unremitting zeal regular discussions of meteor tracks.

The chief discovery that has been positively made is, that luminous meteors are much more regular in their movements than was formerly supposed. The known "radiant points" are no longer confined to the constellations Leo and Camelopardus,

Fig. 251.



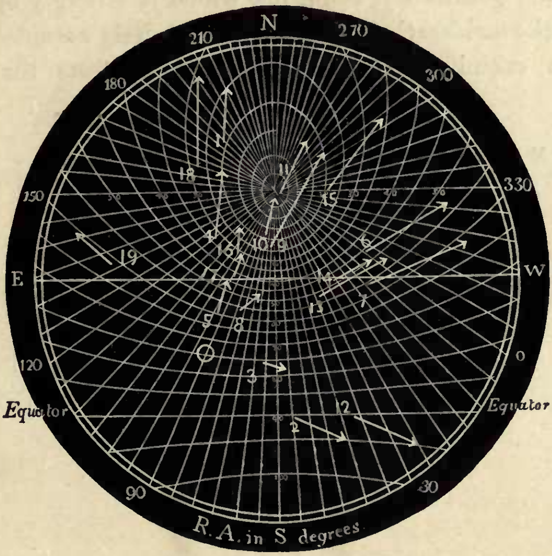
RADIANT POINT OF GEMINIDS (DEC. 12) ON NOV. 28–DEC. 9, 1864.

as they were when Sir J. Herschel wrote the passage which I have quoted on a previous page, but have been found to exist in every quarter of the heavens. A vast number of these systems of meteors must cross the annual path of the Earth, though only a few of these are well known. The observations of a single night have yielded evidence of 50 or 60 different showers in progress at the same time.

A list of the more important radiant points will be found on p. 640, *et seq.* It is based upon a large number of recent observations obtained at Bristol, and the positions will be found fairly accurate, every precaution having been taken to ensure precision. Observers in the Southern hemisphere are much needed, for the Southern Heavens remain comparatively unexplored as regards meteoric Astronomy.

Figs. 251–2 (on pp. 636–7) represent the paths of certain meteors observed at the specified dates. Projected, after the manner of a surveyor's plan, to form a meteor chart, the fact that the meteors really are thrown off from determinate

Fig. 252.



RADIANT POINT OF ORIONIDS (OCT. 18–21) ON OCT. 20, 1865.

centres becomes strikingly apparent. It is unfortunate for the sake of Science that the suddenness with which all these objects appear and the shortness of their duration usually take observers aback, and impair the certainty of their mental impressions, making it often difficult to obtain exactness. The plan of the projection used is that of a plane perspective view, in which the meteor-tracks observed can be represented by straight lines.

It should be the chief aim of future observers to obtain evidence as to the duration of certain meteor showers, and to determine whether their radiant points are variable or stationary in position. Many of the radiant points are apparently fixed relatively to the adjoining stars, and it is important to determine at successive epochs whether these positions are really permanent. If small differences are observable, and such as cannot be attributed to the unavoidable errors of observation, then the nearly accordant radiants are merely due to accidental grouping. But there is a good deal of evidence[1] in support of the opinion that certain radiants are more or less permanent both in activity and position, though this peculiarity, being one which is strongly opposed by theoretical considerations, cannot be definitely accepted until it has been submitted to the most rigorous tests that can be applied.

[1] *Month. Not.*, vol. xlv. p. 93 (Dec. 1884). *Sidereal Messenger*, vol. v. p. 167 (June 1886).

CHAPTER V.

RADIANT POINTS.

Explanation of Reference Letters in the List of Radiant Points.
(pp. 640–643.)

The references in column 7 are—"G.," Greg's General Catalogue published in the *British Association Report* for 1876; "T.," Tupman's Catalogue printed in the *Monthly Notices*, vol. xxxiii. p. 298, March 1873; "S.Z.," Schiaparelli's Catalogue derived from Zezioli's Observations, *British Association Report* for 1878; and "C.," Corder's Catalogue in the *Monthly Notices*, vol. xl. p. 131, Jan. 1880.

LIST OF THE CHIEF RADIANT POINTS

Ref. No.	Date of Shower.	Position of Radiant. R. A. In time.	R. A. In deg.	Decl.	Meridional Position of Radiant by the Stars.	No. in other Catalogues.
		h. m.	°	°		
1	Jan. 2	15 20	230	+53	Quadrans, 12° N.N.E. of β Boötis	G. 6.
2	Jan. 5	9 20	140	+57	Ursa Major, 5° N. of θ	Heis (M. 1).
3	Jan. 9	14 44	221	+42	Boötis, 3° W. of β.	S.Z. 10.
4	Jan. 17	19 40	295	+53	Cygnus, 4° E. of χ	Heis (F. 10).
5	Feb. 15	15 44	236	+11	Serpens, 8° N. of α	T. 10.
6	Feb. 20	12 4	181	+34	Canes Venatici, 10½° E.S.E. of α .	G. 11, T. 4.
7	Feb. 20	17 32	263	+36	Hercules, 3° S.E. of ρ	...
8	March 14	11 40	175	+10	Virgo, 5° S. of β Leonis. . . .	G. 28.
9	March 14	18 40	280	−14	Scutum, 10° S.S.W. of λ Aquilæ .	G. 22.
10	March 24	10 44	161	+58	Ursa Major, 2° N.W. of β . . .	Heis (M. 8).
11	March 27	15 16	229	+32	Corona, 2° W. of θ	S.Z. 48, C. 12.
12	March 28	17 32	263	+62	Draco, 6° S.E. of ζ	...
13	April 18	15 24	231	+17	Serpens, 4° W. of β	G. 53 a.
14	April 19	15 16	229	− 2	Near Libra, 7° N. of β	G. 53, T. 32.
15	April 20	18 0	270	+33	E. of Lyra, 8½° S.W. of α . . .	G. 51, C. 20.
16	April 25	18 8	272	+21	Cerberus, 3° W. of *109. . . .	G. 50.
17	May 1	15 56	239	+46	Hercules, 3° W. of τ.	G. 71, S.Z. 71.
18	May 6	22 32	338	− 2	Aquarius, 1½° S.E. of η	G. 61, T. 33.
19	May 7	16 16	244	+ 7	Ophiuchus, 5° N.N.W. of λ . .	...
20	May 15	19 40	295	± 0	Aquila, 1½° W.S.W. of η . . .	T. 35.
21	May 30	22 12	333	+27	Pegasus, 10° W. of β.	...
22	June 7	16 28	247	−25	Scorpio, 2° N.E. of α	G. 67.
23	June 13	20 40	310	+61	Cepheus, close to η	G. 77, C. 30.
24	June 15	19 0	285	+23	Anser, 8° W.S.W. of β Cygni . .	Sa. 6 (1st Cat.).
25	June 18	20 8	302	+24	Vulpecula, close to *24	C. 74, C. 24.
26	June 20	22 20	335	+57	Cepheus, close to δ	...
27	July 5	1 24	21	+23	Near Aries, 6° N.W. of β . . .	...
28	July 20	17 56	269	+49	Draco, 2° S. of γ	S.Z. 121.
29	July 22	1 4	16	+31	Andromeda, 3° S. of β	...
30	July 23	22 20	335	+49	Lacerta, 8° S. of δ Cephei . . .	G. 68.
31	July 25	3 12	48	+43	Perseus, 4° N.E. of β	S.Z. 137.
32	July 28	22 36	339	−12	Aquarius, 5° N.N.W. of δ . . .	G. 109, T. 43.
33	Aug. 4	2 0	30	+36	Triangulum, 3° N. of β	G. 100, S.Z. 125.
34	Aug. 10	3 4	45	+57	Perseus, 4° N.E. of η	G. 108, C. 39.
35	Aug. 16	4 4	61	+48	Perseus, very close to μ	G. 114, C. 47.

OF METEOR SHOWERS. (From the observations of W. F. DENNING, F.R.A.S.)

No.	NOTES.
1	A rich annual shower. Well observed in 1864. Probable duration Dec. 28 to Jan. 4.
2	Meteors swift with short paths. A very definite shower observed in 1886.
3	A morning shower. Meteors swift with streaks. Observed in 1869 and 1877.
4	Meteors slow and bright. Observed in 1877. Showers here also in Aug. and autumnal months.
5	Radiant sharply defined. Meteors swift with streaks. Observed in 1869 and 1877.
6	A shower of swift, rather bright meteors observed in 1877. Perhaps different to T 4.
7	Visible only in the morning hours. Meteors swift with streaks. Observed in 1877.
8	Meteors slow and brilliant. A radiant of swift meteors here in Feb. and Nov.–Dec.
9	Meteors swift with streaks. Showers of slow meteors from here in July and Aug.
10	Well-defined shower of swift meteors in 1887. Radiants here in Nov. and Dec.
11	Meteors small and swift. Seen in 1887. Radiant sharply defined.
12	Meteors of moderate speed. Many other showers here in May, Aug., Oct., etc.
13	A shower contemporary with the *Lyrids*. Meteors short and quick. Observed in 1885 and 1887.
14	Meteors slow with long paths. Several observers have determined this radiant.
15	*Lyrids*. Meteors swift, the brighter ones leave streaks. Rich display = Comet I, 1861.
16	Meteors short and swift. Observed also by Herschel 1864, April 13, and by Greg, 1872, April 20.
17	Meteors small and short. Well-defined shower in 1886.
18	Rich shower visible before sunrise. Discovered by Tupman. = Halley's comet.
19	Meteors slow. Radiant not very certain. More observations required.
20	Meteors swift with streaks and long paths. Observed in 1877. Radiant here in July?
21	Radiant of swift, streak-leaving meteors, well-defined. Shower here in July.
22	A radiant of slow-moving fireballs. Several seen in 1878.
23	Meteors very swift with streaks. Perhaps connected with Comet I, 1850.
24	Meteors rather slow. Well observed in 1887. A shower here also in April.
25	There are apparently many other showers from this point in the spring and summer.
26	Meteors swift. The radiant seems prolonged in July and September.
27	Meteors very swift with streaks. Observed in 1886. More observations required.
28	Observed in 1873 and 1887. Active radiation from this place in other months.
29	Meteors brilliant with streaks. Centre sharply defined. Observed in 1887.
30	Seen by many observers. Meteors very swift and short. *Lacertids*.
31	Meteors bright, swift and leaving streaks. Rich shower 1884. ? = Comet of 1764.
32	*Aquarids*. Very active display of slowish, long meteors recurring annually.
33	Well-defined shower of swift meteors with streaks. Seen also in Sept. and Oct.
34	*Perseids*. Very rich annual shower. Whole duration July 8 to Aug. 22. Meteors swift, bright and leaving streaks. Radiant shifts from $3° + 49°$ to $76° + 57°$. = Comet III, 1862.
35	Meteors swift with streaks. Active, definite shower in 1877.

LIST OF THE CHIEF RADIANT POINTS

Ref. No.	Date of Shower.	Position of Radiant. R. A. In time.	R. A. In deg.	Decl.	Meridional Position of Radiant by the Stars.	No. in other Catalogues.
		h. m.	°	°		
36	Aug. 21	4 52	73	+41	Auriga, 5° S.W. of α	T. 66.
37	Aug. 22	19 24	291	+60	Draco, 4° E. of ο	G. 78, T. 58.
38	Aug. 25	0 20	5	+11	Pisces, 4° S.E. of γ Pegasi . . .	G. 111, T. 49.
39	Sept. 3	23 36	354	+38	Andromeda, 12° N.N.W. of α . .	Schmidt (354° +43°
40	Sept. 4	23 4	346	± 0	Pisces, 3° S.W. of γ	T. 73, C. 51.
41	Sept. 7	4 8	62	+37	Perseus, 4° S.E. of ε	T. 64, S.Z. 147.
42	Sept. 19	5 0	75	+15	Taurus, 8° E. of α	G. 134, T. 72.
43	Sept. 20	12 48	192	+79	Near Ursa Minor, 8° N.W. of β .	...
44	Sept. 21	2 4	31	+19	Aries, 3° S. of α	C. 70.
45	Sept. 22	4 12	63	+22	Taurus, 4° N.N.W. of ε	...
46	Sept. 30	1 40	25	+71	Custos Messium, close to *f. . .	...
47	Oct. 2	15 0	225	+52	Quadrans, 11° N. of β Boötis . .	...
48	Oct. 4	8 52	133	+79	Camelopardus, 3° E.S.E. of *H 28 .	Heis (N. 15).
49	Oct. 8	2 48	42	+55	Perseus, ¾° E. of η	G. 168.
50	Oct. 8	5 8	77	+31	Taurus, 3½° N.N.W. of β . . .	T. 83.
51	Oct. 11	0 52	13	+ 6	Pisces, 1° S.W. of ε	Backhouse (14°, + 7°
52	Oct. 14	2 40	40	+20	Aries, 3° W. of ε	G. 195.
53	Oct. 14	9 0	135	+68	Ursa Major, 13° W.N.W. of α . .	...
54	Oct. 18	6 8	92	+15	Orion, 2° E. of ν	G. 157, T. 79.
55	Oct. 20	7 4	106	+12	Canis Major, 5° N.W. of β . . .	G. 153, T. 82.
56	Nov. 1	2 52	43	+22	Aries, 1° N. of ε	G. 195.
57	Nov. 2	3 40	55	+ 9	Taurus, close to *e.	T. 91, C. 87.
58	Nov. 13	10 0	150	+22	Leo, 3° W.N.W. of γ.	G. 171, T. 100.
59	Nov. 16	10 16	154	+41	Ursa Major, 1° S. of μ	T. 97.
60	Nov. 17	3 32	53	+71	Camelopardus, close to *H 5 . .	...
61	Nov. 20	4 8	62	+23	Taurus, 5° N.N.W. of ε	G. 156.
62	Nov. 27	1 40	25	+44	Andromeda, 4° N.W. of γ . . .	G. 172, C. 90.
63	Nov. 30	12 40	190	+58	Ursa Major, 2° N.W. of ε . . .	G. 179.
64	Dec. 4	7 20	110	+25	Gemini, 5° S.W. of β.	G. 178, C. 93.
65	Dec. 6	5 20	80	+23	Taurus, 3° N.W. of ζ.	G. 210, C. 95.
66	Dec. 8	9 40	145	+ 7	Leo, 8° S.W. of α	Backhouse(143°, +9°
67	Dec. 8	13 52	208	+71	Draco, 6° N. of α	G. 179 b, C. 92.
68	Dec. 10	7 22	108	+33	Gemini, 3° W.N.W. of α . . .	G. 178, C. 94.
69	Dec. 10	7 48	117	+32	Gemini, 8½° S.S.E. of β	Backhouse(113°, +3
70	Dec. 22	12 56	194	+67	Draco, 7° W. of α	...

OF METEOR SHOWERS.

No.	NOTES.
36	Radiant sharply defined. Meteors swift with streaks. Showers here in Sept. and Oct.
37	A very rich shower of bright slow meteors seen in 1879 and not observed since that year.
38	Meteors very short and slow. Radiants are also here in July and September.
39	Meteors very swift and faint. The chief shower visible in Sept. 1885.
40	Meteors slow and bright with long paths. Radiation from here in earlier months.
41	Well-defined and active display of swift, streak-leaving meteors in 1877, 1885, etc.
42	Meteors very swift with streaks. A morning shower. Also Aug. 25 and Sept. 9.
43	Meteors slow. Observed in 1879. Radiant of swift meteors here, Nov. 29–30, 1886.
44	Active shower of slow meteors seen in 1879. Radiation from here in Aug. and Oct.
45	Meteors very swift with streaks. Observable in the morning hours.
46	Meteors small and short. Many radiants cluster here in July, Aug., Nov., etc.
47	A shower of very brilliant slow meteors in 1877. Further observations are needed.
48	Radiant sharply defined in 1877. Meteors swift with streaks. ? = Comet II, 1825.
49	Meteors slow, sometimes trained. Observed in 1885. Shower here in Dec.
50	Meteors swift with streaks. Two fireballs in 1877. Visible also in Nov. and Dec.
51	Well-defined shower of slow bright meteors 1887. Seen also on Sept. 13, 1885.
52	Very active radiant in 1887. ? = No. 56. Meteors rather swift.
53	Radiant sharply defined in 1887. Meteors swift with streaks. Further observations required.
54	*Orionids.* A very rich shower occurring every year. Whole duration from Oct. 9 to 29. Radiant stationary. Meteors swift with streaks.
55	Meteors very swift with long paths and streaks. A shower here in Dec.
56	An abundant display in 1877. Meteors brilliant and rather slow.
57	Yielded many fine meteors in 1886. Distinct from Taurids of Nov. 20 (No. 61).
58	*Leonids.* Period 33¼ years. Grand displays in 1799, 1833 and 1866, and will reappear in 1899. Furnishes a slight shower every year. Meteors swift with streaks. = Comet I, 1866. The shower continues from Nov. 9 to 17.
59	Meteors very swift and streak-leaving, similar to the Leonids. Well observed in 1885. A rich shower seen here by Booth, Jan. 3, 1889.
60	Well-defined shower in 1886. Radiation also from here in Aug., Sept., Oct.
61	*Taurids.* A well-known shower. Meteors slow. Furnished several fireballs in 1876–7.
62	*Andromedes.* Period about 6½ years. Grand displays in 1872 and 1885. May reappear in 1892 or 1898. Meteors very slow with trains. = Biela's comet. Radiant diffuse.
63	Meteors very swift with streaks. Radiant sharply defined. Observed in 1886.
64	Perhaps connected with the Geminids of Dec. 10, though the radiant is evidently 8° South.
65	A well-defined and active shower of slow meteors observed in 1876 and subsequent years.
66	Meteors very swift with streaks. Sharply defined. Observed in 1877.
67	Meteors rather swift. Further observations required. Possibly = Pons's comet of 1812.
68	*Geminids.* A rich annual shower of swift short meteors. Radiant well defined. Duration from Dec. 1 to 14.
69	Distinct from preceding, though situated only 8° E. of it and visible at same epoch.
70	Meteors swift with streaks. The most active radiant seen in Dec. 1886.

CHAPTER VI.

TELESCOPIC METEORS.

Our knowledge of them limited.—Observations.—Probable heights in the atmosphere.—Showers of telescopic meteors.—Summary of Prof. Safarik's observations and deductions.—Fireball observed in a telescope on Oct. 19, 1863.

WE have now to consider types of meteoric phenomena smaller and probably more distant than the imposing forms visible to the unaided eye. But though generally more minute, they are no doubt identical in character with the conspicuous meteors such as fireballs and ordinary shooting stars.

The observation of telescopic meteors commenced with the invention of that instrument nearly 300 years ago, yet our knowledge of these bodies is very limited. We find occasional references to them in scientific publications, but no one seems to have pursued this particular subject with that method and assiduity which it requires. Those who search for comets or are engaged in observing variable stars frequently notice telescopic meteors, the low powers and large fields usually employed in such cases being suitable for their observation, and it is to be hoped that in future years a special effort will be directed towards gathering more information about them.

In 1795 Schröter saw with his reflecting telescope of 20-inches aperture, a shooting star the height of which he estimated at more than four millions of miles! This is, of course, an enormous exaggeration of the real distance. In 1839, between August 1 and 10, Mason observed 50 telescopic meteors with a reflecting telescope armed with a power of 80. He noticed that their angular velocity was not greater than that of ordinary naked-eye meteors, and he concluded from this that they were situated at great elevations in the atmosphere; in certain instances probably more than 1200 miles. Professor Schiaparelli[a] mentions that he is inclined to believe that the relatively slow velocity is the result of their small mass being unable to overcome the atmospheric resistance, but he does not deny that some falling stars first become visible at least 400 miles above the earth's surface.

Dr. J. F. J. Schmidt stated that during 10 years he recorded 146 telescopic meteors ranging between the 7th and 11th magnitudes. Heis, Hartwig, Luther and others have also observed many of these objects. In the year 1854 Prof. Winnecke recorded no less than 105 on 32 evenings in a 3-inch finder magnifying 15 times and with a field of 3°. Denning has also noticed a considerable number of these small meteors while comet-seeking. He was surprised at the comparative slowness of motion of these bodies. They travel with sufficient leisure across the field to be easily followed by the eye, and their appearance is such as to give the impression of great distance. He concludes that their diminutive size and slow courses are attributable to their remoteness, and computes that they are more numerous than the naked-eye meteors in the proportion of 22 to 1. On Oct. 4, 1881, he noticed a telescopic meteor of the 8th magnitude, which left, for fully 65 seconds, a beautiful narrow streak, showing minute irregularities and reminding one forcibly of a spider's line on a frosty morning[b].

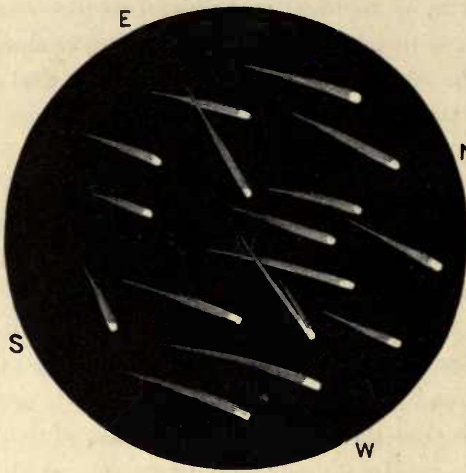
One of the best and most recent observations of these bodies is thus related by Mr. W. R. Brooks:—

"While sweeping on the evening of Nov. 28 [1883] it was my pleasure to observe a wonderful shower or flight of telescopic meteors about 10° above the horizon and near the sunset point. They were very small, none of them visible to the naked eye, most of them leaving a faint train visible in the telescope for 1 or 2 secs. The motion of most of them was to the northward, with an occasional group to the South of the Sun moving southward. . . . The instrument used was my 9-in. reflector, with comet

[a] *Theory of Meteors*, ch. i. § 2, note.
[b] *Observatory*, vol. vi. p. 123. April, 1883.

eye-piece, giving field of $1\frac{1}{2}°$ . . . The faithful comet-seeker frequently in a single night's work encounters numerous telescopic meteors singly, very rarely two at once; but this flight is quite unprecedented in my experience [c]."

Fig. 253.



FLIGHT OF TELESCOPIC METEORS. (*Brooks.*)

Mr. Barnard of Nashville confirms the above remarks, and says that on Dec. 15, 1883, he saw with his telescope small bright bodies close to the Sun. "They were visible at the rate of 5 or 6 per minute, and all moving to the North of East quite rapidly. Occasionally a larger body was seen to flash across the field, blurred by being out of focus. Generally they looked like little stars, many as bright as those of the 1st magnitude." It does not seem to be the case that when naked-eye meteors are frequent, telescopic meteors are also to be seen in proportionate numbers. On Dec. 12, 1877, Prof. Lewis Swift [d] witnessed an abundant display of naked-eye meteors [probably *Geminids*]. He estimated that one observer might have counted 50 per hour between 2^h 30^m A.M. and daybreak. "He was comet-seeking at the time, and noticed a remarkable paucity of telescopic meteors, as during $4\frac{1}{2}$ hours of sweeping he only saw 2 certainly, and one

[c] *Sidereal Messenger*, vol. ii. p. 294. Jan. 1884.

[d] *Science Observer* (Boston), vol. i. p. 46. Feb. 1878.

other suspected, cross the field of his glass, whereas they are generally of frequent occurrence."

Prof. Safarik, the variable-star observer, of Prague, has given a valuable and interesting account of the telescopic meteors he has observed[e]. Writing in 1885 he says:—

"Since 1879 I have been engaged almost exclusively in observations of variable stars, and in that time I have seen hundreds of meteors of every magnitude, from the 2nd down to the 12th, passing through the field of my ·6½in. reflector (ordinary power 32, field 54′) or its 1½-in. finder. To me they are so common that it would be difficult to pass a night at a low-power telescope of large aperture without having caught sight of a couple of them. On Aug. 30, 1880, I noted in my observing book: 'It would be difficult to tell the number of telescopic meteors which passed to-night (between 9^h and 15^h) the field of my telescope or its finder; I think more than 50, if not nearly 100.' And on the subsequent night (9^h to 14^h): 'To-night also numerous telescopic and some naked-eye meteors seen; less than last night, about 20, many of them only diffused luminosities.' I had no time to register the tracks in the Bonn Star Maps, though I am sure that after a little practice it might be done with considerable accuracy."

Prof. Safarik classifies telescopic meteors as follows:—

(1.) Well-defined star-like objects of very small diameter, round, or of no recognisable shape, sometimes with smoky luminous trails of cometary aspect—*i.e.* widening as they recede from the principal body.

(2.) Large luminous bodies of some minutes of arc in diameter, round or ovoid, sometimes pretty well defined, ordinarily diffused and smoky, with wedge-shaped tails, fading as they recede from the body.

(3.) Well-defined discs of a very perceptible diameter, almost invariably brighter at the border than at the centre, which gives them the aspect of hollow transparent shells, or luminous bubbles. When they happen to travel slowly across the field in an horizontal direction they look very much like soap-bubbles driven by wind.

(4.) Faint diffused nebulous masses of irregular shape, considerable size, and different colours.

In Class 1. Safarik places an object of very peculiar character, which he saw on April 24, 1874, at about $3\frac{1}{2}^h$ P.M. He was

[e] *Astronomical Register*, vol. xxiii. pp. 205–6. Sept. 1885.

observing the moon (nearly illuminated $\frac{3}{4}$ths) in bright sunshine, with a 4-inch refractor, when he was surprised by the apparition, on the disc of the moon, of a dazzling white star, which travelled slowly from E.S.E. to W.N.W., and after leaving the bright disc shone on the deep blue sky like Sirius or Vega in daylight and fine air. It is well known that luminous star-like objects are seen in summer time near the Sun. Schwabe gave much attention to them, and called them "Lichtflocken." It is generally admitted now that they are partly the *pappus* of various seeds, partly convolutions of the Gossamer, floating high in the air and brilliantly illuminated by the Sun when nearly in the line between the Sun and the eye. Schröter saw something of the kind at night (Oct. 15, 1789), when scrutinising the unilluminated part of the Moon with his 7ft reflector, power 161. Suddenly a "splash of light," as he calls it, consisting of small sharp sparks of light, was formed on the disc of the Moon, and crossed the rest of the disc and field in 2 secs.; and before it had left the field, there was formed another splash nearly at the same place and which left the field in the same direction. Numerous telescopic bodies of very small diameter and moving rapidly across the Moon, or near it, were also seen by the Abbo Lamey in 1864 and 1873[f].

Safarik gives numerous examples of the various classes of telescopic meteors, and concludes with the following remarks:—"In our mineralogical museums hundreds of meteoric stones are preserved and have been thoroughly studied in modern times. They present a great variety of types, from pure compact iron through hard crystalline silicate rocks to porous friable masses easily broken with the fingers. The identity of falling stars and meteorites has been doubted by some physicists, but Schiaparelli regards their arguments against identity as insufficient, and so we may admit that the matter which constitutes falling stars is similar to that of bolides. Now if we try to establish a relation between the different known classes

[f] *Les Mondes*, Nov. 20, 1873.

of meteorites and our four classes of telescopic meteorites we may describe it thus:—

"I. Solid bodies, small, very compact and refractory, not easily disaggregated by the enormous pressure they suffer on entering the terrestrial atmosphere; little or no occulted gases; the smoke accompanying part of them may consist of the superficial melted layer torn off and dispersed by the friction of the atmosphere; (hard stony meteorites).

"II. Bodies larger than Class I., of a less compact material, which is easily melted and torn off by the mighty current of air produced by their rapid flight; another part of their envelope and trail may consist of vapours and gases; (tufaceous and conglomeratic stony meteorites).

"III. Small very compact and refractory masses, rich in occulted gas, which is expelled by their sudden enormous calefaction, and expands almost equally in every direction, presenting thus the appearance of a ball; (siderites).

"IV. Clouds of cosmical dust or meteorites, so soft and friable that they are crushed and converted into dust as soon as the pressure of the atmosphere begins to act upon them."

These deductions are interesting, and will doubtless be tested by new observations which can hardly fail to throw some further light on the subject. Prof. Herschel has also called attention to the desirability of ascertaining whether telescopic meteors are principally seen only at low apparent altitudes and moderate real heights, or whether they appear with equal frequency at all angular altitudes above the horizon, and therefore at all possible heights above the earth's surface to which the use of astronomical telescopes enables us to extend our sight[g].

The showers of telescopic meteors witnessed by Brooks and Barnard in March and December, 1883, were very noteworthy, and Denning has suggested that they were connected with the remarkable sun-glows which attracted so much attention at that

[g] *Report of the Luminous Meteor Committee of the British Association,* 1878, p. 116.

period; but this idea seems to me at variance with what we know otherwise as to the cause of these glows.

Perhaps the most striking observation ever recorded of a meteor seen by means of a telescope was by Schmidt on Oct. 19, 1863, when he followed a fireball for 14 seconds. This meteor was double-headed, and was closely attended by a number of smaller meteors advancing together with parallel motions. [See Fig. 241, Plate XXXVI.] Though not a telescopic meteor properly so called, it merits description from its curious, multiple character, and the inference suggested, that could instrumental observations of bolides be greatly increased, we might often find that, instead of a solitary compact mass, the nucleus is really composed of a number of bodies revolving closely together in concentric orbits.

BOOK VI.

TABLES OF THE PLANETS.

Planet.	Symbol.	λ	π	☊	ι	φ	ε	Sec. Var. π	Sec. Var. ☊	Sec. Var. ι
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″		″	″	″
Mercury ...	☿	112 16 4	74 20 42	45 57 38	7 0 5	11 51 30	0·2054925	+ 643·56	− 782·27	+ 18·1828
Venus	♀	146 44 56	128 43 6	74 51 41	3 23 29	0 23 37	0·0068722	− 267·60	− 1869·80	− 4·5522
Earth	⊕	100 53 30	99 30 29	0 0 0	0 0 0	0 57 43	0·0167917	+ 1177·81	...	...
Mars.........	♂	233 5 34	332 22 51	47 59 38	1 51 6	5 20 25	0·0931125	+ 1582·43	− 2328·44	− 0·1523
Jupiter	♃	81 54 49	11 7 38	98 25 45	1 18 52	2 45 37	0·0481626	+ 663·86	− 1577·57	− 22·6087
Saturn	♄	123 6 29	89 8 20	111 56 7	2 29 36	3 13 6	0·0561501	+ 1943·07	− 2266·46	− 15·5131
Uranus.. ...	♅	173 30 37	167 30 24	72 59 21	0 46 28	2 40 23	0·0466686	+ 238·62	− 3597·76	+ 3·1331
Neptune ...	♆	335 8 58	47 14 37	130 6 52	1 46 59	0 29 58	0·0087195	?	?	?
Sun	☉	...	...	...	...	...	...	...	...	...
Moon	☽	118 17 8	266 10 7	13 53 17	5 8 40	3 8 37	0·0549081	° ′ ″ 40 39 45	° ′ ″ 16 19 42	0

Symbol.	Sec. Var. ε	Semi-Axis Major. ⊕ = 1.	Daily Hel. Motion.	Sidereal Period.		Equinoctial P.	Synodic P.	Distance from ☉.		
								Max.	Min.	Mean.
			° ′ ″	d.	y.	d.	d.	Miles.	Miles.	Miles.
☿	+ 0·000003867	0·3870985	4 5 32	87·969	0·240	87·968	115·87	43,347,000	28,569,000	35,958,000
♀	− 0·000062711	0·7233317	1 36 7	224·700	0·615	224·695	583·92	67,652,000	66,728,000	67,190,000
⊕	+ 0·000041632	1·000000	0 59 8	365·256	1·000	365·242		94,450,000	91,330,000	92,890,000
♂	+ 0·000090176	1·523691	0 31 26	686·979	1·880	686·929	779·82	154,714,000	128,358,000	141,536,000
♃	+ 0·000159350	5·202798	0 4 59	4332·584	11·862	4330·610	398·8	506,563,000	460,013,000	483,288,000
♄	− 0·000312402	9·538852	0 2 0	10759·219	29·458	10746·732	378·0	931,033,000	841,097,000	886,065,000
♅	− 0·000025072	19·182730	0 0 42	30686·820	84·018	30589·357	369·7	1,865,107,000	1,698,781,000	1,781,944,000
♆	?	30·036280	0 0 21	60126·710	164·622	59742·710	367·5	2,816,094,000	2,767,406,000	2,791,750,000
☉	...	...	...	...	...	...	...	...	...	...
☽	0	—	13 10 35	27·32166	0·082	27·32158	29·53058	From ⊕. 251,947	From ⊕. 225,719	From ⊕. 238,833

*** These Tables are based upon an assumed solar parallax of 8·80″, which is probably correct within 0·02″ or 0·03″.

Symbol.	Distance from ⊕ at Sup. ☌ for Inf. Planets, or at ☌ for Sup. Planets.			Distance from ⊕ at Inf. ☌ for Inf. Planets, or at ☍ for Sup. Planets			Apparent Diameter. From ⊕			Apparent Diameter. From ☉	Real Diameter.	
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Mean.	⊕ = 1.	Miles.
	Miles.	Miles.	Miles.	Miles	Miles.	Miles.	″	″	″	″		
☿	137,797,000	119,899,000	128,848,000	65,881,000	47,983,000	56,932,000	12·9	4·5	8·7	17·3	0·380	3,008
♀	162,102,000	158,058,000	160,080,000	27,722,000	23,678,000	25,700,000	65·2	9·5	37·3	23·0	0·944	7,480
⊕	...	...	...	...	...	...	...	...	...	17·6	1·000	7,926
♂	249,164,000	219,688,000	234,426,000	63,384,000	33,908,000	48,646,000	30·4	4·1	17·3	7·3	0·631	4,999
♃	601,013,000	551,343,000	576,178,000	415,233,000	365,563,000	390,398,000	49·9	30·4	40·1	37·7	11·159	88,439
♄	1,025,483,000	932,427,000	978,955,000	839,703,000	746,647,000	793,175,000	20·7	15·1	17·9	17·5	9·488	75,036
♅	1,959,557,000	1,790,111,000	1,874,834,000	1,773,777,000	1,604,331,000	1,689,054,000	3·5	3·2	3·4	3·6	3·896	30,875
♆	2,910,544,000	2,858,736,000	2,884,640,000	2,724,764,000	2,672,956,000	2,698,860,000	2·9	2·6	2·8	2·7	4·621	37,205
							′ ″	′ ″	′ ″			
☉	—	—	—	—	—	—	32 35	31 31	32 3	—	109·299	866,200
☽	—	—	—	—	—	—	33 31	29 21	31 26	4·8	0·272	2,160

Symbol.	Surface.		Volume.		Mass.			Density.	
	⊕ = 1.	Square Miles.	⊕ = 1.	Cubic Miles.	☉ = 1.	⊕ = 1.	Tons.	⊕ = 1.	Water. = 1.
☿	0·144	28,431,000	0·055	14,255,000,000	$\frac{1}{5000000}$	0·066	401,000,000,000,000,000,000	1·26	7·17
♀	0·891	175,783,000	0·841	219,149,000,000	$\frac{1}{425000}$	0·782	4,746,000,000,000,000,000,000	0·92	5·21
⊕	1·000	197,309,000	1·000	260,613,000,000	$\frac{1}{332260}$	1·000	6,069,000,000,000,000,000,000	1·00	5·67
♂	0·398	78,503,000	0·251	65,403,000,000	$\frac{1}{3098500}$	0 107	649,000,000,000,000,000,000	0·45	2·54
♃	124·533	24,571,480,000	1389·715	362,178,000,000,000	$\frac{1}{1048}$	317·042	1,924,124,000,000,000,000,000,000	0·23	1·29
♄	89·649	17,688,537,000	848·820	221,217,083,000,000	$\frac{1}{3502}$	94·877	575,808,000,000,000,000,000,000	0·11	0·63
♅	15 179	2,994,879,000	59·135	15,411,422,000,000	$\frac{1}{22600}$	14·702	89,226,000,000,000,000,000,000	0·25	1·41
♆	21·352	4,348,570,000	103·466	26,964,528,000,000	$\frac{1}{19380}$	17·145	1,040,630,000,000,000,000,000,000	0·17	0·94
☉	11946·332	2,357,127,702,000	1,305,725·526	340,289,375,000,000,000	1	332,260·000	2,016,486,047,000,000,000,000,000,000	0·25	1·44
☽	0·074	14,657,402	0.02034	5,300,000,000	$\frac{1}{24490744}$	0·0128	78,000,000,000,000,000,000	0·63	3·57

Symbol.	Apparent Diameter of ☉ to observer on Planet.			Light and Heat of ☉	Axial Rotation.			Inclination of Axis to Plane of Ecliptic.		Polar Compression.	Force of Gravity.		Orbital Velocity.			Velocity of Rotation at Equator.		Time required for falling into the Sun, were gravitation free to exert its influence alone.
	′	″	⊕ = 1.	⊕ = 1.	h.	m.	s.	°	′		Fall: Feet in 1 sec.	⊕ = 1.	Miles per hour.	Feet per sec.	⊕ = 1.	Miles per hour.	Feet per sec.	Days.
☿	82	49	2·583	6·67	24	5	30	63	?	$\frac{1}{29}$	7·60	0·47	107,012	156,952	1·607	392	575	15·6
♀	44	19	1·384	1·91	23	21	23	73	32	very small	14·00	0·87	78,284	114,816	1·176	1,006	1,474	39·7
⊕	32	3	1·000	1·00	23	56	4	66	32	$\frac{1}{299}$	16·08	1·00	66,579	97,650	1·000	1,040	1,526	64·6
♂	21	2	0·656	0·43	24	37	23	61	18	$\frac{1}{55}$	4·46	0·28	53,938	79,109	0·810	638	935	121·5
♃	6	10	0·192	0·037	9	55	21	86	55	$\frac{1}{16·8}$	40·98	2·55	29,203	42,831	0·439	28,001	41,068	766·0
♄	3	22	0·105	0·011	10	29	17	61	50	$\frac{1}{9·22}$	18·53	1·15	21,560	31,622	0·324	22,476	32,965	1902·3
♅	1	40	0·052	0·003	9	30	?	?		?	13·62	0·85	15,202	22,297	0·228	10,210	14,975	5425·8
♆	1	4	0·033	0·001		?		?		?	12·91	0·80	12,156	17,828	0·183	?	?	10640·2
					d.	h.	m.											
☉	...		...	...	25	7	48	82	30	very small, if any.	461·62	28·71	...	...	...	4,477	6,567	...
☽	...		...	...	27	7	43	88	30	?	2·48	0·15	2,273	3,334	0·033	10	15	—

*** The epoch of the shifting elements on p. 651 is January 0, 1800 for the planets, and January 0, 1801 for the Moon.

The following elements of the planets Uranus and Neptune are by Professor Newcomb:—

		Uranus.			Neptune.
Epoch		1850.0 G.	Epoch		1850·0 G.
		° ′ ″			° ′ ″
λ	=	29 12 43	λ	=	335 5 38
π	=	170 38 48	π	=	43 17 30
☊	=	73 14 37	☊	=	130 7 31
ι	=	0 46 20	ι	=	1 47 0
ε	=	0·0463592	ε	=	0·0084962
a	=	19·18338	a	=	30·11157
Mean annual motion				=	2·18470°
Period	=	30688·5076 days		=	60186·6385 days 164·7820 Julian years.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
1	Ceres.........	1801, Jan. 1	Piazzi	Palermo	148 1	80 50	10 37
2	Pallas	1802, March 28	Olbers	Bremen	122 3	172 48	34 44
3	Juno	1804, Sept. 1	Harding	Lilienthal ..	55 18	170 43	13 2
4	Vesta.........	1807, March 29	Olbers	Bremen	251 32	103 32	7 8
5	Astræa	1845, Dec. 8	Hencke	Driesen	134 46	141 31	5 19
6	Hebe	1847, July 1	Hencke	Driesen	15 12	138 46	14 48
7	Iris............	— Aug. 13	Hind	London	41 23	259 48	5 28
8	Flora	— Oct. 18	Hind	London	32 54	110 18	5 53
9	Metis.........	1848, April 25	Graham	Markree	71 4	68 32	5 36
10	Hygeia	1849, April 12	De Gasparis	Naples.........	237 58	285 21	3 48
11	Parthenope	1850, May 11	De Gasparis	Naples.........	318 31	125 16	4 38
12	Victoria......	— Sept. 13	Hind	London	301 39	235 35	8 23
13	Egeria	— Nov. 2	De Gasparis	Naples...... .	120 10	43 12	16 32
14	Irene	1851, May 19	Hind	London	179 43	86 52	9 8
15	Eunomia ...	— July 29	De Gasparis	Naples..	27 52	293 52	11 44
16	Psyche	1852 March 17	De Gasparis	Naples.........	13 53	150 38	3 4
17	Thetis	— April 17	Luther.........	Bilk.....	262 5	125 16	5 37
18	Melpomene	— June 24	Hind	London	15 6	150 4	10 9
19	Fortuna......	— Aug. 22	Hind	London	31 1	211 20	1 33
20	Massilia ...	— Sept. 19	De Gasparis	Naples.........	100 9	206 30	0 41
21	Lutetia	— Nov. 15	Goldschmidt	Paris	327 4	80 28	3 5
22	Calliope......	— Nov. 16	Hind	London	58 12	66 39	13 44
23	Thalia	— Dec. 15	Hind	London	123 36	67 50	10 14
24	Themis	1853, April 5	De Gasparis	Naples.........	143 27	35 32	0 48
25	Phocea	— April 6	Chacornac ...	Marseilles ...	302 48	214 16	21 36
26	Proserpine	— May 5	Luther.........	Bilk	236 25	45 55	3 36
27	Euterpe.. ...	— Nov. 8	Hind	London	87 59	93 51	1 36
28	Bellona	1854, March 1	Luther.........	Bilk...........	124 5	144 40	9 21
29	Amphitrite	— March 1	Marth	London	56 23	356 41	6 7
30	Urania	— July 22	Hind	London	31 59	308 5	2 6
31	Euphrosyne	— Sept. 1	Ferguson.. ...	Washington	92 48	31 40	26 29
32	Pomona.....	— Oct. 26	Goldschmidt	Paris	193 22	220 43	5 29
33	Polyhymnia	— Oct. 28	Chacornac ...	Paris	343 26	9 14	1 55
34	Circe	1855, April 6	Chacornac ..	Paris	141 18	184 47	5 27
35	Leucothea...	— April 19	Luther.........	Bilk...........	201 30	355 52	8 12

ε	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕'s = 1.	Miles			
0·0790	771	4·60	2·767	196	7·4	1887, Sept. 30·0...	Godward.
0·2405	770	4·61	2·769	171	8·0	1888, Dec. 5·0 ...	Farley.
0·2563	814	4·36	2·669	124	8·7	1887, Sept. 30·0 ...	Hind.
0·0883	978	3·63	2·362	214	6·5	1888, Sept. 24·0...	Farley.
0·1880	857	4·14	2·577	57	9·9	— Jan. 27·0 ...	Farley.
0·2025	940	3·78	2·425	92	8·5	— Jan. 17·0 ...	R. Luther.
0·2309	963	3·69	2·386	88	8·4	1850, Jan. 0·0......	Brünnow.
0·1567	1086	3·27	2·201	61	8·9	1848, Jan. 1·0......	Brünnow.
0·1233	962	3·69	2·387	76	8·9	1858, June 30·0 ..	Lesser.
0·1175	639	5·58	3·137	103	9·5	1888, Mar. 27·0 ...	E. Becker.
0·1002	924	3·84	2·452	63	9·5	1888, Jan. 17·0 ...	R. Luther.
0·2170	995	3·57	2·334	51	9·7	1831, Jan. 0·0......	Brünnow.
0·0872	858	4·14	2·576	60	9·7	1850, Jan. 0·0......	Hansen.
0·1613	852	4·17	2·589	65	9·7	1888, Feb. 16·0 ...	Maywald.
0·1874	825	4·30	2·644	92	8·6	1854, Jan. 0·0......	Schubert.
0·1357	709	4·99	2·925	75	9·6	1888, May 25·0 ...	Schubert.
0·1299	913	3·89	2·472	50	10·1	— July 25·0 ...	Maywald.
0·2176	1020	3·48	2·296	51	9·3	1854, Jan. 0·0......	Schubert.
0·1596	930	3·82	2·442	56	9·8	1887, Dec. 18.0 ...	Berberich.
0·1432	948	3·74	2·410	65	9·2	1888, May 25·0 ...	Küstner.
0·1627	934	3·80	2·436	39	10·1	1853, Jan. 2·0......	Lesser.
0·1031	715	4·96	2·909	78	9·8	1888, Jan. 7·0.....	Berberich.
0·2309	832	4·27	2·630	47	10·5	— Apr. 15·0 ...	Schubert.
0·1337	641	5·55	3·129	24	10·8	— Nov. 2·0 ...	Krüger.
0·2540	954	3·72	2·400	36	10·5	1887, Sept. 29·0...	Berberich.
0·0874	820	4·33	2·656	44	10·5	1853, June 11·0...	Hoek.
0·1739	987	3·60	2·347	50	9·7	1873, Jan. 5·0......	Hoppe.
0·1510	767	4·63	2·777	65	10·1	1888, July 25·0 ..	Bruhns.
0·0741	869	4·08	2·555	83	9·0	1855, Jan. 0·0.. ...	Becker.
0·1282	976	3·64	2·365	44	9·9	1889, Mar. 2·0 ..	Günther.
0·2238	635	5·59	3·147	46	11·0	1888, Dec. 11·0 ...	Schubert.
0·0831	853	4·16	2·587	42	10·6	1855, Jan. 0·0.....	Lesser.
0·3333	729	4·84	2·871	36	11·8	1888, Nov. 1·0 ...	Schubert.
0·1094	806	4·40	2·686	29	11·5	— Nov. 2·0 ...	Auwers.
0·2247	686	5·17	2·992	38	12·2	— Sept. 22·0 ...	Schubert.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
36	Atalanta ..	1855, Oct. 5	Goldschmidt	Paris	43 9	359 5	18 40
37	Fides	— Oct. 5	Luther.........	Bilk...........	66 36	8 18	3 6
38	Leda	1856, Jan. 12	Chacornac ...	Paris	100 27	296 28	6 58
39	Lætitia	— Feb. 8	Chacornac ...	Paris	2 45	157 23	10 22
40	Harmonia ...	— March 31	Luther.........	Bilk...........	0 54	93 35	4 16
41	Daphne	— May 22	Goldschmidt	Paris	221 21	178 50	15 55
42	Isis	— May 23	Pogson.........	Oxford.........	318 4	84 27	8 35
43	Ariadne......	1857, April 15	Pogson.........	Oxford.........	278 17	264 40	3 28
44	Nysa	— May 27	Goldschmidt	Paris	111 54	131 8	3 42
45	Eugenia ...	— June 28	Goldschmidt	Paris	232 31	148 4	6 35
46	Hestia	— Aug. 16	Pogson.........	Oxford.........	354 12	181 30	2 18
47	Melete	— Sept. 9	Goldschmidt	Paris	295 11	194 0	8 3
48	Aglaia	— Sept. 15	Luther.........	Bilk...........	315 30	3 58	5 1
49	Doris	— Sept. 19	Goldschmidt	Paris	72 2	185 2	6 30
50	Pales	— Sept. 19	Goldschmidt	Paris	31 40	290 39	3 8
51	Virginia......	— Oct. 4	Ferguson......	Washington	10 29	173 39	2 49
52	Nemausa ...	1858, Jan. 22	Laurent	Nismes	174 27	175 45	9 57
53	Europa	— Feb. 6	Goldschmidt	Paris	106 3	129 42	7 26
54	Calypso	— April 4	Luther.........	Bilk...........	92 53	144 3	5 7
55	Alexandra...	— Sept. 10	Goldschmidt	Paris	295 39	313 45	11 48
56	Pandora ...	— Sept. 10	Searle	Albany, U.S.	11 44	10 57	7 13
57	Mnemosyne	1859, Sept. 22	Luther.........	Bilk...........	52 3	200 0	15 12
58	Concordia ...	1860, March 24	Luther.........	Bilk...........	189 10	161 20	5 2
59	Danaë	— Sept. 9	Goldschmidt	Châtillon......	343 57	334 9	18 16
60	Olym.(Elpis)	— Sept. 12	Chacornac ...	Paris	18 40	170 41	8 37
61	Erato	— Sept. 14	Förster.........	Berlin	38 59	125 46	2 12
62	Echo	— Sept. 14	Ferguson......	Washington	99 15	191 58	3 45
63	Ausonia......	1861, Feb. 10	De Gasparis	Naples.........	270 40	337 57	5 47
64	Angelina ...	— March 4	Tempel	Marseilles ...	124 57	310 56	1 19
65	Cybele	— March 8	Tempel	Marseilles ...	259 5	158 50	3 29
66	Maia	— April 9	H. P. Tuttle	Cambridge, U.S.	48 0	8 25	3 5
67	Asia	— April 17	Pogson	Madras	306 23	202 50	5 59
68	Hesperia ...	— April 29	Schiaparelli	Milan	110 19	186 44	8 31
69	Leto	— April 29	Luther.........	Bilk...........	346 4	45 0	7 58
70	Panopea ...	— May 5	Goldschmidt	Châtillon......	309 39	48 14	11 38

ε	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕'s = 1.	Miles.			
0·3002	780	4·55	2·746	18	12·0	1889, Mar. 1·0......	Schubert.
0·1762	825	4·30	2·645	47	10·4	1888, May 25·0 ...	Schubert.
0·1544	782	4·54	2·741	40	11·4	1886, Oct. 24·0 ...	Berberich.
0·1144	771	4·63	2·767	90	9·5	1888, Jan. 27·0 ...	Tietjen.
0·0465	1039	3·41	2·267	61	9·2	1863, Jan. 0·0......	Schubert.
0·2661	771	4·62	2·767	61	10·5	1888, Feb. 16·0 ...	Berberich.
0·2227	930	3·81	2·441	39	10·4	1887, Aug. 20·0 ...	L. Becker.
0·1679	1085	3·27	2·203	33	10·0	1889, Jan. 1·0......	Prey.
0·1530	942	3·77	2·421	42	9·8	1888, Aug. 14·0 ...	Powalky.
0·0825	791	4·49	2.721	44	10·7	— Apr. 16·0 ...	Richter.
0·1659	884	4·01	2·525	25	10·6	1888, May 6·0 ...	Karlinski.
0·2340	847	4·18	2·599	29	11·7	1887, Dec. 28·0 ...	R. Luther.
0·1328	726	4·88	2·880	43	11·2	1889, Feb. 10·0 ...	Powalky.
0·0628	645	5·52	3·115	57	10·9	1888, Apr. 16·0 ...	Powalky.
0·2289	652	5·44	3·094	61	11·0	1887, Mar. 2·0 ...	Powalky.
0·2882	823	4·32	2·649	25	11·7	1889, Feb. 10·0 ...	Powalky.
0·0674	975	3·64	2·365	38	9·8	1888, July 25·0 ...	Berberich.
0·1135	652	5·44	3·093	72	10·3	— Sept. 23·0 ...	Murmann.
0·2048	837	4·24	2·620	29	11·5	— Mar. 7·0 ...	Tietjen.
0·1999	796	4·47	2·710	40	10·9	1884, Aug. 15·0 ...	Schultz.
0·1446	774	4·58	2·759	44	10·8	1885, Jan. 22·0 ...	Moeller.
0·1175	635	5·59	3·150	63	10·7	1888, Dec. 12·0 ...	Adolph.
0·0425	800	4·43	2·704	31	11·6	1865, Jan. 7·0......	Oppolzer.
0·1662	689	5·15	2·982	38	11·0	1888, Jan. 17·0 ...	R. Luther.
0·1172	794	4·47	2·713	36	10·9	1865, Jan. 7·0......	Oppolzer.
0·1757	643	5·53	3·124	40	12·3	1877, Sept. 21·0...	Oppolzer.
0·1825	958	3·70	2·394	17	11·1	1888, Feb. 16·0 ...	C. H. F. Peters.
0·1253	957	3·71	2·395	49	9·9	— July 25·0 ...	Tietjen.
0·1242	808	4·39	2·682	44	10·5	1887, Jan. 12·0 ...	Oppolzer.
0·1031	558	6·36	3·430	63	11·0	1888, Aug. 14·0 ...	Fritsche.
0·1728	823	4·31	2·648	18	12·2	1887, April 2·0 ...	Maywald.
0·1865	942	3·77	2·420	22	11·2	1888, Aug. 14·0 ...	Frischauf.
0·1645	689	5·15	2·983	32	10·7	1880, Mar. 29·0 ...	Kowalczyk.
0·1851	764	4·64	2·783	60	10·5	1879, May 14·0 ...	T. Wolff.
0·1814	839	4·23	2·615	36	10·9	1874, Jan. 0·0......	Dunér.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	°	° ′
71	Feronia ...	1861, May 29	C.H.F. Peters	Clinton, U.S....	308 25	207 50	5 24
72	Niobe	— Aug. 13	Luther.........	Bilk	222 7	316 19	23 17
73	Clytie	1862, April 7	Tuttle	Cambridge, U.S.	57 10	7 42	2 24
74	Galatea ...	— Aug. 30	Tempel	Marseilles	8 11	197 59	4 0
75	Eurydice ...	— Sept. 22	C.H.F. Peters	Clinton, U.S....	335 33	359 59	5 0
76	Freia	— Oct. 21	D'Arrest	Copenhagen ...	90 43	212 12	2 3
77	Frigga......	— Nov. 15	C.H.F. Peters	Clinton, U.S....	59 40	2 11	2 28
78	Diana	1863, March 15	Luther.........	Bilk	121 42	333 58	8 40
79	Eurynome	— Sept. 14	Watson	AnnArbor, U.S.	44 26	206 41	4 37
80	Sappho ...	1864, May 2	Pogson.........	Madras	355 32	218 36	8 38
81	Terpsichore	— Sept. 30	Tempel	Marseilles	49 4	2 23	7 55
82	Alcmene ...	— Nov. 27	Luther.........	Bilk	131 40	26 58	2 51
83	Beatrix ...	1865, April 26	De Gasparis	Naples	191 36	27 34	5 0
84	Clio	— Aug. 25	Luther.........	Bilk	339 55	327 26	9 21
85	Io............	— Sept. 19	C.H.F. Peters	Clinton, U.S....	323 57	203 39	11 54
86	Semele......	1866, Jan. 4	Tietjen.........	Berlin	28 55	87 51	4 47
87	Sylvia	— May 17	Pogson.........	Madras	334 11	75 53	10 55
88	Thisbe	— June 15	C.H.F. Peters	Clinton, U.S....	309 10	277 36	5 15
89	Julia	— Aug. 6	Stephan	Marseilles	353 59	311 44	16 12
90	Antiope ...	— Oct. 1	Luther.........	Bilk	301 12	71 25	2 17
91	Ægina......	— Nov. 4	Stephan	Marseilles	81 28	10 57	2 8
92	Undina ...	1867, July 7	C.H.F. Peters	Clinton, U.S....	327 47	102 53	9 56
93	Minerva ...	— Aug. 24	Watson	AnnArbor, U.S.	276 39	4 55	8 35
94	Aurora ...	— Sept. 6	Watson	AnnArbor, U.S.	45 39	4 17	8 4
95	Arethusa ..	— Nov. 23	Luther.........	Bilk	34 33	244 3	12 56
96	Ægle	1868, Feb. 17	Coggia.........	Marseilles	161 46	322 57	16 6
97	Clotho	— Feb. 17	Tempel	Marseilles	65 33	160 43	11 46
98	Ianthe	— April 18	C.H.F. Peters	Clinton, U.S....	148 43	354 15	15 32
99	Dike.........	— May 29	Borrelly	Marseilles	240 54	42 2	13 53
100	Hecate......	— July 11	Watson	AnnArbor, U.S.	306 18	128 14	6 23
101	Helena	— Aug. 15	Watson	AnnArbor, U.S.	327 0	343 39	10 10
102	Miriam ...	— Aug. 22	C.H.F. Peters	Clinton, U.S....	354 42	211 45	5 5
103	Hera ...	— Sept. 7	Watson	AnnArbor, U.S.	320 55	136 13	5 24
104	Clymene ...	— Sept. 13	Watson	AnnArbor, U.S.	60 21	43 39	2 54
105	Artemis ...	— Sept. 16	Watson	AnnArbor, U.S.	242 46	188 6	21 31

ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M.T.	Calculator.
	″	Years.	⊕'s = 1.			
0·1202	1040	3·41	2·266	11·2	1886, Oct. 24·0 ...	C. H. F. Peters.
0·1768	776	4·57	2·754	10·7	1888, July 5·0 ...	E. Becker.
0·0442	816	4·35	2·665	12·0	1886, Nov. 13·0 ...	Powalky.
0·2383	766	4·63	2·778	11·8	1888, May 26·0 ...	Maywald.
0·3029	811	4·37	2·674	11·6	— Aug. 14·0 ...	Stockwell.
0·1688	562	6·32	3·418	12·0	1889, Jan. 21·0 ...	Murmann.
0·1331	814	4·37	2·668	11·1	1888, Sept. 3·0 ...	Plath.
0·2088	837	4·24	2·619	10·6	1882, Sept. 15·0 ...	Dubjago.
0·1934	928	3·82	2·444	10·5	1886, Oct. 22·0 ...	Lachmann.
0·2008	1020	3·48	2·296	10·6	1888, June 15·0 ...	A. Leman.
0·2102	736	4·83	2·854	11·8	1888, Sept. 3·0 ...	Maywald.
0·2218	772	4·59	2·764	11·7	1887, Nov. 28·0 ...	W. Luther.
0·0848	936	3·78	2·432	11·3	1888, May 26·0 ...	E. Becker.
0·2354	977	3·63	2·362	11·3	1889, Feb. 10·0 ...	Maywald.
0·1934	821	4·32	2·654	10·9	1887, Nov. 28·0 ...	Groeben.
0·2201	650	5·46	3·101	12·4	1889, Feb. 10·0 ...	Maywald.
0·0947	546	6·50	3·481	11·9	1888, Nov. 22·0 ...	Plath.
0·1642	771	4·60	2·766	10·8	1883, Oct. 20·0 ...	Kowalczyk.
0·1803	871	4·07	2·551	10·1	— Dec. 19·0 ...	T. Wolff.
0·1613	636	5·58	3·147	11·6	1888, Aug. 14·0 ...	Maywald.
0·1083	852	4·16	2·589	11·3	1889, Apr. 11·0 ...	Maywald.
0·1011	623	5·70	3·188	10·9	1884, Dec. 13·0 ...	Anderson.
0·1409	776	4·57	2·755	10·8	1886, Nov. 13·0 ...	Lehmann.
0·0825	631	5·62	3·163	11·3	1883, July 12·0 ...	Leppig.
0·1492	661	5·37	3·067	11·3	1888, Aug. 14·0 ...	Schur.
0·1363	665	5·33	3·052	11·4	1887, Nov. 8·0 ...	Schulhof.
0·2571	814	4·35	2·669	10·6	1888, Nov. 2·0 ...	Maywald.
0·1917	806	4·40	2·686	11·6	— Nov. 22·0 ...	C. H. F. Peters.
0·2385	759	4·68	2·797	14·0	1868, June 5·0 ...	Löwy & Tisserand.
0·1673	654	5·44	3·087	11·9	1888, Mar. 7·0 ...	Stark.
0·1392	854	4·15	2·585	10·7	— June 15·0 ...	Watson.
0·2529	818	4·34	2·660	12·6	— May 6·0 ...	C. H. F. Peters.
0·0814	799	4·44	2·701	10·2	— Feb. 16·0 ...	Leveau.
0·1556	633	5·60	3·156	12·2	— May 6·0 ...	Watson.
0·1759	971	3·66	2·372	11·1	1889, Feb. 10·0 ...	A. Leman.

No.	Name.	Discovered on	Discovered by	Discovered at	π	Ω	ι
					° ′	° ′	° ′
(106)	Dione	1868, Oct. 10	Watson	AnnArbor, U.S.	26 8	63 20	4 38
(107)	Camilla ...	— Nov. 17	Pogson.........	Madras	111 2	175 59	9 52
(108)	Hecuba ...	1869, April 2	Luther.........	Bilk	169 58	352 21	4 24
(109)	Felicitas ...	— Oct. 9	C.H.F. Peters	Clinton, U.S....	56 53	4 33	8 1
(110)	Lydia	1870, April 19	Borrelly	Marseilles	336 19	57 14	6 0
(112)	Ate	— Aug. 14	C.H.F. Peters	Clinton, U.S....	110 13	306 23	4 56
(111)	Iphigenia	— Sept. 19	C.H.F. Peters	Clinton, U.S....	338 3	324 2	2 37
(113)	Amalthæa	1871, March 12	Luther.........	Bilk	200 1	123 8	5 2
(114)	Cassandra	— July 23	C.H.F. Peters	Clinton, U.S....	153 24	164 25	4 54
(115)	Thyra	— Aug. 6	Watson	AnnArbor, U.S.	43 0	309 11	11 35
(116)	Sirona	— Sept. 8	C.H.F. Peters	Clinton, U.S....	152 47	64 25	3 35
(117)	Lomia	— Sept. 12	Borrelly	Marseilles	48 6	349 33	14 58
(118)	Peitho	1872, March 15	Luther	Bilk	78 33	47 32	7 47
(119)	Althæa ...	— April 3	Watson	AnnArbor, U.S.	11 26	203 56	5 44
(120)	Lachesis ...	— April 10	Borrelly	Marseilles	223 0	342 40	6 59
(121)	Hermione	— May 12	Watson	AnnArbor, U.S.	357 17	76 55	7 36
(122)	Gerda	— July 31	C.H.F. Peters	Clinton, U.S....	200 46	178 52	1 36
(123)	Brunhilda	— July 31	C.H.F. Peters	Clinton, U.S....	69 13	308 31	6 25
(124)	Alceste...	— Aug. 23	C.H.F. Peters	Clinton, U.S....	247 30	188 23	2 56
(125)	Liberatrix	— Sept. 11	ProsperHenry	Paris	276 8	169 26	4 38
(126)	Velleda ...	— Nov. 5	Paul Henry	Paris	348 43	23 19	2 56
(127)	Johanna ...	— Nov. 5	ProsperHenry	Paris	119 58	31 49	8 16
(128)	Nemesis ...	— Nov. 25	Watson	AnnArbor, U.S.	15 47	76 38	6 16
(129)	Antigone...	1873, Feb. 5	C.H.F. Peters	Clinton, U.S....	242 13	137 44	12 10
(130)	Electra ...	— Feb. 17	C.H.F. Peters	Clinton, U.S....	20 25	146 5	22 57
(131)	Vala	— May 24	C.H.F. Peters	Clinton, U.S....	220 39	65 25	4 58
(132)	Æthra ...	— June 13	Watson	AnnArbor, U.S.	152 45	259 53	24 57
(133)	Cyrene ...	— Aug. 16	Watson	AnnArbor, U.S.	241 32	321 12	7 14
(134)	Sophrosyne	— Sept. 27	Luther.........	Bilk	67 20	346 24	11 36
(135)	Hertha ...	1874, Feb. 18	C.H.F. Peters	Clinton, U.S. ...	320 32	344 0	2 18
(136)	Austria ...	— March 1	Palisa	Pola	316 15	186 15	9 33
(137)	Melibœa ...	— April 21	Palisa	Pola	309 35	203 43	13 21
(138)	Tolosa	— May 19	Perrotin	Toulouse	310 1	54 48	3 14
(139)	Juewa	— Oct. 10	Watson	Pekin............	164 31	352 27	10 57
(140)	Siwa	— Oct. 13	Palisa	Pola	300 7	107 6	3 12

ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator
	″	Years.	⊕'s = 1.			
0·1754	629	5·64	3·167	11·3	1888, May 6·0 ...	Tietjen.
0·0692	544	6·53	3·491	11·2	1887, Feb. 21·0 ...	Matthiessen.
0·1048	618	5·74	3·206	11·7	1888, Aug. 14·0...	Schulhof.
0·2977	802	4·43	2·696	12·0	1887, Dec. 18·0 ...	Groeben.
0·0808	786	4·51	2·732	10·5	1888, Feb. 16·0 ...	H. Oppenheim.
0·1045	850	4·17	2·593	11·3	1887, Sept. 9·0 ...	Holetschek.
0·1282	934	3·80	2·435	11·5	1888, July 25·0 ...	Tietjen.
0·0866	969	3·66	2·376	11·0	— Jan. 17·0 ...	W. Luther.
0·1374	810	4·38	2·677	11·1	— July 5·0 ...	Anton.
0·1934	966	3·67	2·380	10·4	1886, May 26·0 ...	Watson.
0·1412	770	4·62	2·769	10·7	1880, Sept. 25·0 ...	H. Oppenheim.
0·0294	686	5·17	2·991	11·4	1887, Nov. 28·0 ...	Tietjen.
0·1610	931	3·81	2·439	10·8	1888, May 26·0 ...	Holetschek.
0·0825	856	4·15	2·580	10·6	— Jan. 27·0 ...	Berberich.
0·0541	645	5·50	3·118	11·7	— Feb. 17·0 ...	Plath.
0·1262	552	6·42	3·456	11·2	1887, Nov. 8·0 ...	Berberich.
0·0451	614	5·78	3·221	11·5	1888, May 6·0 ...	Lange.
0·1219	802	4·43	2·694	11·8	— March 7·0...	Berberich.
0·0779	832	4·27	2·629	10·3	— March 27·0	Hall.
0·0787	781	4·54	2·743	11·2	— Jan. 27·0 ...	Lange.
0·1054	932	3·82	2·439	11·5	1887, Sept. 9·0 ...	Groeben.
0·0645	776	4·57	2·756	10·5	1888, Mar. 27·0...	Maywald.
0·1288	777	4·56	2·752	10·6	1886, Dec. 23·0 ...	A. Palisa.
0·2136	731	4·87	2·866	10·3	1888, Mar. 7·0 ...	Austin.
0·2142	645	5·50	3·115	10·6	— Nov. 22.0 ...	Powalky.
0.0686	936	3·77	2·432	12·2	— May 6·0 ...	Berberich.
0·3832	846	4·19	2·600	11·1	1881, Jan. 3·0 ...	Watson.
0·1418	663	5·35	3·061	11·3	1888, May 26·0 ...	Maywald.
0·1161	864	4·12	2·565	11·1	— May 6·0 ...	Maywald.
0·2039	938	3·78	2·428	10·5	1889, Feb. 10·0 ...	Maywald.
0·0848	1026	3·46	2·286	11·2	1879, Dec. 10·0 ...	H. Oppenheim.
0·2142	643	5·53	3·124	11·8	1887, Nov. 28·0 ...	Tietjen.
0·1619	926	3·83	2·449	11·8	1888, Feb. 6·0 ...	Plath.
0·1777	766	4·63	2·780	10·9	— Dec. 12·0 ...	Berberich.
0·2162	786	4·51	2·731	11·4	1883, Oct. 20·0 ...	Maywald.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
141	Lumen	1875, Jan. 13	Paul Henry...	Paris	13 47	319 13	11 58
142	Polana	— Jan. 28	Palisa	Pola	221 6	292 5	2 14
143	Adria.........	— Feb. 23	Palisa	Pola	221 31	333 49	11 29
144	Vibilia	— June 3	C.H.F. Peters	Clinton, U.S.	7 29	76 46	4 48
145	Adeona	— June 3	C.H.F. Peters	Clinton, U.S.	118 59	77 43	12 41
146	Lucina	— June 8	Borrelly	Marseilles......	227 23	84 16	13 6
147	Protogeneia	— July 10	Schulhof	Vienna	23 34	251 15	1 54
148	Gallia	— Aug. 7	ProsperHenry	Paris	36 6	145 8	25 19
149	Medusa	— Sept. 21	Perrotin	Toulouse	246 49	160 15	1 6
150	Nuwa.........	— Oct. 19	Watson	AnnArbor,U.S.	355 27	207 45	2 8
151	Abundantia	— Nov. 1	Palisa	Pola	164 46	38 54	6 28
152	Atala.........	— Nov. 2	Paul Henry...	Paris	82 21	41 33	12 12
153	Hilda.........	— Nov. 2	Palisa	Pola	284 35	228 23	7 53
154	Bertha	— Nov. 6	ProsperHenry	Paris	190 59	37 34	20 59
155	Scylla	— Nov. 8	Palisa	Pola	82 14	43 4	14 4
156	Xantippe ...	— Nov. 22	Palisa	Pola	156 9	246 23	7 29
157	Dejanira ...	— Dec. 1	Borrelly	Marseilles......	107 32	62 38	12 2
158	Coronis	1876, Jan. 4	Knorre.........	Berlin	61 58	280 55	1 0
159	Æmilia	— Jan. 26	Paul Henry...	Paris	101 32	135 8	6 4
160	Una	— Feb. 20	C.H.F. Peters	Clinton, U.S.	57 50	9 12	3 51
161	Athor.........	— April 18	Watson	AnnArbor,U.S.	310 42	18 35	9 3
162	Laurentia ...	— April 21	ProsperHenry	Paris	145 11	38 6	6 5
163	Erigone	— April 26	Perrotin	Toulouse	93 58	159 14	4 41
164	Eva	— July 12	Paul Henry...	Paris	359 29	77 36	24 25
165	Loreley	— Aug. 10	C.H.F. Peters	Clinton, U.S.	279 56	304 5	11 11
166	Rhodope ...	— Aug. 10	C.H.F. Peters	Clinton, U.S.	30 32	129 34	12 0
167	Urda	— Aug. 28	C.H.F. Peters	Clinton, U.S.	295 0	166 27	2 11
168	Sibylla	— Sept. 27	Watson	AnnArbor,U.S.	17 10	209 24	4 34
169	Zelia	— Sept. 28	ProsperHenry	Paris	327 1	354 43	5 31
170	Maria or Myrrha	1877, Jan. 10	Perrotin	Toulouse	96 40	301 22	14 23
171	Ophelia	— Jan. 13	Borrelly	Marseilles......	144 49	101 16	2 34
172	Baucis	— Feb. 5	Borrelly	Marseilles......	329 2	331 57	10 2
173	Ino...........	— Aug. 2	Borrelly	Marseilles......	13 33	148 39	14 16
174	Phædra	— Sept. 3	Watson	AnnArbor,U.S.	253 46	328 53	12 8
175	Andromache	— Oct. 1	Watson	AnnArbor,U.S.	293 8	23 42	3 47

e	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕'s = 1.			
0·2136	816	4·35	2·664	11·4	1888, Feb. 16·0 ...	Berberich.
0·1331	943	3·76	2·419	12·2	1885, Dec. 28·0 ..	L. Becker.
0·0724	773	4·57	2·762	12·4	1880, Mar. 29·0 ..	Haerdol.
0·2329	819	4·33	2·657	10·7	1888, July 18·0 ...	Powalky.
0·1438	811	4·38	2·675	11·3	— May 6·0 ...	Tietjen.
0·0663	792	4·48	2·719	11·1	— Apr. 16·0 ...	Berberich.
0·0308	639	5·54	3·137	12·5	— Dec. 12·0 ...	L. Becker.
0·1834	768	4·62	2·773	11·0	— July 25·0 ...	L. Becker.
0·1193	1139	3·12	2·133	12·9	— Sept. 30·5 ...	Tietjen.
0·1305	690	5·15	2·980	11·6	1884, May 25·5 ...	H. Oppenheim.
0·0369	851	4·17	2·591	11·7	1887, Sept. 9·0 ..	Knopf.
0·0814	638	5·54	3·139	12·2	1888, Jan. 7·0 ..	Lange.
0·1676	449	7·90	3·968	12·6	— June 15·0 ...	Kühnert.
0·0787	621	5·71	3·197	11·2	1887, Dec. 18·0 ...	Anton.
0·2557	714	4·97	2·913	13·5	1875, Nov. 8·5 ...	Schulhof.
0·2636	670	5·29	3·038	11·9	— Nov. 27·5 ...	A. Schmidt.
0·2105	855	4·15	2·583	14·7	— Dec. 27·5 ...	A. Leman.
0·0541	731	4·86	2·868	12·3	1888, July 25·0 ...	Maywald.
0·1022	648	5·48	3·107	12·3	— Mar. 7·0 ...	Berberich.
0·0680	788	4·52	2·728	11·8	— Nov. 22·0 ...	Neugebauer.
0·1377	967	3·67	2·379	11·0	— Sept. 3·0 ...	Tietjen.
0·1819	676	5·25	3·019	12·3	1887, June 1·0 ...	Tietjen.
0·1567	981	3·61	2·356	12·0	1876, May 26·5 ...	A. Leman.
0·3464	831	4·27	2·633	11·5	1888, Apr. 16·0 ...	Richter.
0·0703	640	5·54	3·132	11·1	— Nov. 2·0 ...	Samter.
0·2110	805	4·40	2·687	12·5	— May 26·0 ...	Richter.
0·0340	737	4·82	2·852	13·0	1889, Apr. 11·0 ...	Lange.
0·0753	573	6·20	3·372	11·6	1888, Sept. 3·0 ...	Groeben.
0·1302	980	3·62	2·358	11·3	1887, Nov. 8·0 ...	Richter.
0·0648	870	4·08	2·554	11·7	1888, Dec. 12·0 ...	A. Leman.
0·1161	636	5·58	3·145	12·1	— Jan. 7·0 ...	Berberich.
0·1141	967	3·67	2·379	10·4	— Feb. 16·0 ...	Berberich.
0·2073	782	4·54	2·742	11·0	— Apr. 16·0 ...	Becka.
0·1406	733	4·84	2·861	11·6	1886, June 26·5 ...	H. Oppenheim.
0·3478	540	6·57	3·507	11·2	1883, July 12·0 ...	Watson.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
176	Idunna	1877, Oct. 14	C.H.F. Peters	Clinton, U.S.	22 48	201 8	22 37
177	Irma	— Nov. 5	Paul Henry	Paris	22 40	349 19	1 27
178	Belisana ...	— Nov. 6	Palisa	Pola	262 40	50 51	1 55
179	Clytemnestra	— Nov. 12	Watson	AnnArbor,U.S.	355 40	253 13	7 47
180	Garumna ...	1878, Jan. 29	Perrotin	Toulouse	124 23	314 38	0 53
181	Eucharis ...	— Feb. 2	Cottenot	Marseilles......	95 17	144 51	18 36
182	Elsa	— Feb. 7	Palisa	Pola	54 59	106 36	2 10
183	Istria.........	— Feb. 8	Palisa	Pola	45 3	142 46	26 31
184	Deiopeia ...	— Feb. 28	Palisa	Pola	171 39	335 44	1 12
185	Eunike	— March 1	C.H.F.Peters	Clinton, U.S.	15 4	153 51	23 14
186	Celuta	— April 6	ProsperHenry	Paris	327 53	14 37	13 11
187	Lamberta ...	— April 11	Coggia.........	Marseilles......	214 9	22 20	10 43
188	Menippe ...	— June 18	C.H.F.Peters	Clinton, U.S.	309 48	241 55	11 21
189	Phthia	— Sept 9	C.H.F.Peters	Clinton, U.S.	9 47	203 25	5 9
190	Ismene	— Sept. 22	C.H.F.Peters	Clinton, U.S.	106 27	177 5	6 7
191	Kolga	— Sept. 30	C.H.F.Peters	Clinton, U.S.	24 51	159 55	11 29
192	Nausikaa ...	1879, Feb. 17	Palisa	Pola	10 58	343 17	6 52
193	Ambrosia ...	— Feb. 28	Coggia.........	Marseilles......	71 10	351 24	11 36
194	Prokne	— Mar. 21	C.H.F.Peters	Clinton, U.S.	319 18	159 25	18 23
195	Eurykleia...	— April 22	Palisa	Pola	118 21	7 53	7 0
196	Philomela...	— May 14	C.H.F.Peters	Clinton, U.S.	309 26	73 24	7 16
197	Arete.........	— May 21	Palisa	Pola	314 15	82 4	8 50
198	Ampella ...	— June 13	Borrelly	Marseilles......	355 29	268 38	9 20
199	Byblis	— July 9	C.H.F.Peters	Clinton, U.S.	261 40	90 0	15 23
200	Dynamene	— July 27	C.H.F.Peters	Clinton, U.S.	48 2	325 18	6 55
201	Penelope ...	— Aug. 7	Palisa	Pola	335 6	157 8	5 43
202	Chryseis ...	— Sept. 11	C.H.F.Peters	Clinton, U.S.	132 9	137 51	8 48
203	Pompeia ...	— Sept. 25	C.H.F.Peters	Clinton, U.S.	44 40	348 41	3 12
204	Callisto	— Oct. 8	Palisa	Pola	256 59	205 46	8 17
205	Martha	— Oct. 13	Palisa	Pola	24 27	212 17	10 40
206	Hersilia......	— Oct. 13	C.H.F.Peters	Clinton, U.S.	85 41	145 16	3 46
207	Hedda	— Oct. 17	Palisa	Pola	218 57	28 56	3 49
208	Lacrimosa...	— Oct. 21	Palisa	Pola	127 49	5 22	1 47
209	Dido	— Oct. 22	C.H F.Peters	Clinton, U.S.	255 55	2 5	7 14
210	Isabella......	— Nov. 12	Palisa	Pola	44 8	32 58	5 18

ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	″	Years.	⊕'s = 1.			
0·1683	625	5·68	3·183	12·1	1888, Aug. 14·0 ...	Neugebauer.
0·2363	770	4·60	2·769	12·4	— Jan. 7·0 ...	Richter.
0·0430	919	3·86	2·461	12·0	1887, Apr. 22·0 ...	Berberich.
0·1132	693	5·12	2·971	11·5	1886, June 26·5 ...	H. Oppenheim.
0·1672	789	4·51	2·725	13·3	1888, May 26·0 ...	Groeben.
0·2193	644	5·51	3·121	11·5	1887, Oct. 19·0 ...	De Ball.
0·1884	945	3·76	2·416	11·0	1888, Nov. 22·0 ...	Samter.
0·3511	757	4·69	2·801	12·6	1878, Mar. 2·5 ...	Douner.
0·0680	624	5·69	3·186	12·4	1885, June 11·0 ...	Thraen.
0·1255	782	4·53	2·740	10·4	1888, May 26·0 ...	Groeben.
0·1503	978	3·63	2·362	11·4	— Jan. 7·0 ...	Tietjen.
0·2405	788	4·52	2·727	11·4	1887, Apr. 2·0 ...	A. Leman.
0·2173	749	4·74	2·821	13·0	1878, July 5·5 ...	A. Leman.
0·0369	925	3·84	2·451	11·5	1885, July 1·5 ...	H. Oppenheim.
0·1622	453	7·83	3·944	12·0	1887, Dec. 18·0 ...	Küstner.
0·0863	719	4·94	2·898	12·0	1886, Apr. 7·0 ...	L. Becker.
0·2447	952	3·73	2·403	9·3	1888, July 25·0 ...	Lange.
0·2854	858	4·14	2·576	12·2	1879, Mar. 25·5 ...	A. Leman.
0·2375	838	4·23	2·618	10·5	1888, June 15·0 ...	Tietjen.
0·0417	727	4·89	2·878	12·3	— Feb. 16·0 ...	Tietjen.
0·0125	645	5·50	3·116	10·3	1887, Oct. 19·0 ...	Tietjen.
0·1617	783	4·53	2·739	12·7	— Feb. 21·0 ...	Lange.
0·2261	920	3·86	2·460	11·1	1888, Nov. 22·0 ...	A. Leman.
0·1704	626	5·67	3·179	12·4	1887, Dec. 18·0 ...	Tietjen.
0·1337	784	4·53	2·737	11·0	1888, July 25·0 ...	Groeben.
0·1785	809	4·39	2·679	11·9	— Nov. 2·0 ...	Richter.
0·0964	657	5·40	3·078	10·7	— May 6·0 ...	Berberich.
0·0593	784	4·53	2·736	11·7	— Sept. 23·0 ...	Berberich.
0·1719	812	4·38	2·672	12·0	1886, Feb. 26·0 ...	A. Palisa.
0·0334	766	4·63	2·779	12·7	— Feb. 26·0 ...	Küstner.
0·0407	782	4·53	2·740	12·0	1887, June 21·0 ...	Stechert.
0·0288	1028	3·45	2·284	11·8	1888, Apr. 16·0 ...	Richter.
0·0160	722	4·91	2·891	12·1	— Aug. 14·0 ...	Berberich.
0·0659	636	5·58	3·144	11·6	— Apr. 16·0 ...	Groeben.
0·1239	790	4·50	2·722	12·5	— Nov. 2·0 ...	Berberich.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
(211)	Isolda	1879, Dec. 10	Palisa.........	Pola	75 28	265 14	3 51
(212)	Medea	1880, Feb. 6	Palisa	Pola	56 47	315 6	4 17
(213)	Lilæa	— Feb. 16	C.H.F.Peters	Clinton, U.S.	282 5	122 23	6 47
(214)	Aschera	— March 1	Palisa	Pola	108 17	342 33	3 27
(215)	Œnone	— April 7	Knorre	Berlin	343 27	25 20	1 43
(216)	Cleopatra ...	— April 10	Palisa	Pola	32 4	215 52	13 2
(217)	Eudora	— Aug. 30	Coggia.........	Marseilles......	314 24	164 1	10 17
(218)	Bianca	— Sept. 4	Palisa	Pola	230 9	170 56	15 12
(219)	Thusnelda...	— Sept. 30	Palisa	Pola	340 27	200 52	10 47
(220)	Stephania ...	1881, May 19	Palisa	Vienna	333 35	258 26	7 34
(221)	Eos............	1882, Jan. 18	Palisa	Vienna	330 34	142 39	10 51
(222)	Lucia.........	— Feb. 9	Palisa	Vienna	257 32	80 17	2 11
(223)	Rosa	— March 9	Palisa	Vienna	104 3	49 5	1 59
(224)	Oceana	— Mar. 30	Palisa	Vienna	269 30	353 24	5 52
(225)	Henrietta ...	— April 19	Palisa	Vienna	299 36	200 46	20 43
(226)	Weringia ...	— July 19	Palisa	Vienna	285 19	135 24	15 49
(227)	Philosophia	— Aug. 12	Paul Henry...	Paris	225 55	330 56	9 15
(228)	Agathe	— Aug. 19	Palisa	Vienna	329 23	313 18	2 23
(229)	Adelinda ...	— Aug. 22	Palisa	Vienna	333 37	30 48	2 10
(230)	Athamantis	— Sept. 3	De Ball	Bothkamp......	16 44	239 40	9 26
(231)	Vindobona	— Sept. 10	Palisa	Vienna	253 22	352 51	5 10
(232)	Russia	1883, Jan. 31	Palisa	Vienna	200 25	152 34	6 4
(233)	Asterope ...	— May 11	Borrelly	Marseilles......	344 22	222 29	7 39
(234)	Barbara......	— Aug. 12	C.H.F.Peters	Clinton, U.S.	333 53	144 12	15 21
(235)	Carolina ...	— Nov. 28	Palisa	Vienna	269 40	66 33	9 4
(236)	Honoria......	1884, April 26	Palisa	Vienna	356 58	186 29	7 37
(237)	Cœlestina ...	— June 27	Palisa	Vienna	281 55	84 36	9 47
(238)	Hypatia......	— July 1	Knorre	Berlin	29 12	184 32	12 22
(239)	Adrastea ...	— Aug. 18	Palisa	Vienna	26 5	181 49	6 8
(240)	Vanadis ...	— Aug. 27	Borrelly	Marseilles......	51 54	115 0	2 6
(241)	Germania ...	— Sept. 12	Luther.........	Düsseldorf......	341 0	272 21	5 31
(242)	Kriemhild...	— Sept. 22	Palisa	Vienna	123 2	207 58	11 17
(243)	Ida............	— Sept. 29	Palisa	Vienna	72 41	326 20	1 10
(244)	Sita	— Oct. 14	Palisa	Vienna	13 6	208 37	2 50
(245)	Vera	1885, Feb. 6	Pogson.........	Madras	27 13	62 12	5 11

ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕ s' = 1.			
0·1564	666	5·32	3·049	11·5	1887, July 11·0 ...	A. Palisa.
0·1108	646	5·49	3·112	12·2	1888, Aug. 14·0 ...	L. Becker.
0·1438	776	4·57	2·754	11·7	1887, Dec. 18·0 ...	A. Leman.
0·0317	841	4·22	2·612	12·1	1886, Sept. 14·0 ...	L. Becker.
0·0359	771	4·60	2·766	12·8	1888, Jan. 7·0 ...	Groeben.
0·2507	760	4·67	2·794	10·1	1886, June 26·0 ...	Knopf.
0·3093	730	4·86	2·868	13·1	1888, Mar. 7·0 ...	Richter.
0·1164	814	4·37	2·667	11·3	— May 26·0 ...	Groeben.
0·2241	983	3·61	2·354	11·2	1884, Nov. 23·0 ...	Darmer.
0·2571	985	3·60	2·350	13·6	1887, Jan. 0·5 ...	Bidschof.
0·1028	679	5·23	3·011	11·2	1888, Apr. 16·0 ...	Groeben.
0·1475	642	5·54	3·127	12·9	— Apr. 16·0 ...	Berberich.
0·1179	651	5·45	3·098	13·3	— May 6·0 ...	Groeben.
0·0425	825	4·30	2·644	11·7	1887, July 11·0 ...	S. Oppenheim.
0·2650	566	6·27	3·398	12·7	1884, Dec. 16·5 ...	Cerulli.
0·2022	793	4·47	2·715	13·0	1887, Nov. 28·0 ...	Kreutz.
0·2099	639	5·53	3·137	12·9	1888, Sept. 23·0 ...	Lange.
0·2405	1087	3·26	2·201	14·7	1882, Aug. 24·5 ...	Kreutz.
0·1518	564	6·29	3·406	13·5	1888, July 5·0 ...	Berberich.
0·1659	965	3·68	2·382	10·3	— Mar. 7·0 ...	Richter.
0·1507	710	4·94	2·922	12·4	1887, July 31·0 ...	Lange.
0·1747	870	4·08	2·552	13·4	— Apr. 2·5 ...	Herz.
0·0996	817	4·34	2·662	11·3	— Apr. 2·0 ...	Knopf.
0·2428	962	3·69	2·386	11·7	— Nov. 8·0 ...	Tietjen.
0·0572	725	4·89	2·882	12·2	— Aug. 20·0 ...	Tietjen.
0·1893	758	4·68	2·799	11·4	1885, July 22·5 ...	Bidschof.
0·0742	773	4·59	2·763	12·8	1887, Jan. 12·0 ...	Oppolzer.
0·0863	714	4·97	2·911	11·7	1888, May 26·0 ...	Berberich.
0·2284	689	5·15	2·981	14·2	— May 6·0 ...	Berberich.
0·2065	815	4·36	2·666	12·5	1884, Nov. 10·5 ...	Saint-Blancat.
0·0999	665	5·33	3·053	11·4	1888, May 6·0 ...	W. Luther.
0·1218	733	4·84	2·863	12·6	1884, Sept. 26·5 ...	Herz.
0·0430	733	4·84	2·862	13·3	1887, Jan. 1·5 ...	Herz.
0·1374	1106	3·21	2·175	13·7	— Sept. 9·0 ...	Berberich.
0·1960	649	5·47	3·104	12·5	— May 2·0 ...	Saint-Blancat.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
246	Asporina ...	1885, Mar. 6	Borrelly	Marseilles......	256 6	162 35	15 38
247	Eukrate ...	— Mar. 14	Luther.........	Düsseldorf......	53 40	0 20	25 9
248	Lameia	— June 5	Palisa	Vienna	249 6	246 37	4 1
249	Ilse	— Aug. 16	C.H.F.Peters	Clinton, U.S.	13 57	334 48	9 41
250	Bettina	— Sept. 3	Palisa	Vienna	88 7	26 9	12 57
251	Sophia	— Oct. 4	Palisa	Vienna	77 47	157 20	10 26
252	Clementina	— Oct. 11	Perrotin	Nice	355 2	203 23	10 1
253	Mathilde ...	— Nov. 12	Palisa	Vienna	333 42	180 6	6 37
254	Augusta ...	1886, Mar. 31	Palisa	Vienna	258 19	28 13	4 37
255	Oppavia......	— Mar. 31	Palisa	Vienna	162 8	14 6	9 34
256	Walpurga ...	— Apr. 3	Palisa	Vienna	228 48	183 43	13 15
257	Silesia	— Apr. 5	Palisa	Vienna	65 16	35 30	3 40
258	Tyche	— May 4	Luther.........	Düsseldorf......	359 27	207 41	14 14
259	Aletheia ...	— June 28	C.H.F.Peters	Clinton, U.S.	239 49	88 34	10 43
260	Huberta ...	— Oct. 3	Palisa	Vienna	336 17	168 47	6 16
261	Prymno......	— Oct. 31	C.H.F.Peters	Clinton, U.S.	259 48	96 20	3 38
262	Valda.........	— Nov. 3	Palisa	Vienna	60 29	38 43	7 45
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ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M.T.	Calculator.
	″	Years.	⊕'s=1.			
0·1050	802	4·43	2·695	11·7	1885, Apr. 18·5 ...	A doyer.
0·2406	782	4·53	2·740	11·0	1887, Sept. 29·0...	Lange.
0·0657	914	3·89	2·471	13·0	1888, Jan. 27·0 ...	Berberich.
0·2161	967	3·66	2·379	13·6	— May 6·0 ...	Berberich.
0·1285	634	5·60	3·153	11·7	1885, Dec. 8·0 ...	Mönnichmeyer.
0·1071	645	5·47	3·115	13·6	— Nov. 10·5 ...	Knopf.
0·0834	634	5·60	3·153	13·0	— Oct. 30·5 ...	Tietjen.
0·2620	824	4·31	2·647	13·4	1888, Jan. 7·0 ...	Lebeuf.
0·1161	1086	3·27	2·202	13·4	1886, Apr. 2·5 ...	Schwarz.
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0·1217	644	5·52	3·119	12·8	— Apr. 5·5......	Berberich.
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0·1170	638	5·54	3·139	12·1	1886, July 1·5 ...	Tietjen.
0·1103	548	6·48	3·475	13·9	— Oct. 4·5	Berberich.
0·0897	997	3·56	2·331	11·9	1887, Jan. 12·0 ...	Lange.
0·2133	873	4·06	2·547	14·1	1886, Nov. 6·5 ...	Berberich.
0·0814	724	4·90	2·885	13·3	— Nov. 13·0 ...	Lange.
0·1580	771	4·61	2·767	12·1	1887, Jan. 1·5 ...	Millosevich.
0·2616	942	3·77	2·421	13·8	— Apr. 17·5 ...	Berberich.
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0·2023	838	4·23	2·617	13·0	1887, Nov. 12·5 ...	Berberich.
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0·1032	682	5·26	3·004	12·7	— Nov. 14·0 ...	Knopf.
				13·5		
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				13·0		
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No.	Name.	Discovered. on	Discovered. by	Discovered. at	π	☊	ι
					° ′	° ′	° ′
(281)	Lucretia ...	1888, Oct. 31	Palisa	Vienna	45 56	31 0	5 19
(282)		1889, Jan. 28	Charlois	Nice			
(283)		— Feb. 8	Charlois	Nice			

ε	μ	Period.	Semi-axis, Major.	App. opp. Star Mag.	Epoch. Berlin M.T.	Calculator.
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