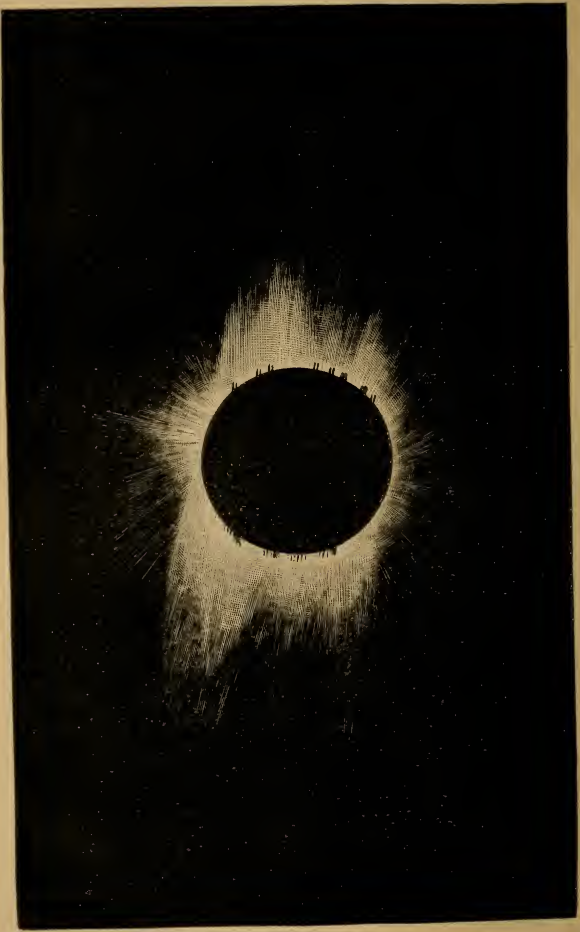
ASTRONOMY

OLD AND NEW



FRONTISPIECE.—Fig. 1.—Photograph of total Solar Eclipse taken by the party of Professor Pritchett, of Washington University, St. Louis, Mo., at Norman, Cal., on January 1, 1889.

ASTRONOMY,

NEW AND OLD.

BY

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PREFACE.

THE main object of this book is to give an epitome of the vast science of Astronomy in the simplest and most concise manner possible.

The utmost fairness is aimed at throughout, and particularly in the treatment of the history and different hypotheses of the science.

There have been for some time past two sciences of Astronomy recognized, the "Old" and the "New." The majestic Old Astronomy traces its descent back through the great Hipparchus to the earliest dawn of tradition. The Old Astronomy has been called the most perfect of the sciences. It reached its lofty standard of perfection, step by step, by subjecting every new advance to the rigid requirements of mathematical accuracy.

The New Astronomy sprung up beside the Old about thirty years ago, and is, really, the science of Celestial Physics. The new science is more brilliant and fascinating than the old; it is much more winsome, because easier of approach.

However, the new and the old science are daily coming closer together. The spectroscope and celestial photography lend themselves directly to dynamical inquiries, and thus help to form the future science of sidereal mechanics, which will be the product of the fusing of the "New" and the "Old" Astronomy.

To give an intelligent summary of the great science, it is necessary to blend together, in some measure, the Old and New Astronomies. Mathematics, however, is avoided as much as possible, and only introduced in its simplest form, and when absolutely necessary.

The major part of the book is devoted to the fresh young science of Celestial Physics.

Every topic of importance in Astronomy is treated. A short history of the science is given, from its dawn to the present. Considerable space is given to that important portion of practical Astronomy, the division of time. The principal uses of the two great instruments of the astronomer, the telescope and spectroscope, are shown. The constitutions of the Sun and Planets have received careful consideration. The interesting subjects of Comets, Shooting-stars, and the Constellations are not forgotten. Particular attention has been devoted to the Zodiacal Light, Celestial Photography, the Habitability of the Planets, and the great Hypothesis of Laplace.

THE AUTHOR.

CHAPTER I.

HISTORY.

Astronomy (ἄστρον, a star, and νόμος, a law) teaches all that is known of the heavenly bodies. It is the oldest of the sciences, and reaches back to the earliest twilight of tradition.

The Hindoos, Chinese, and Egyptians lay claim to a very high antiquity in this study; but it has been demonstrated that these claims are utterly unreliable. Their cultivation of celestial objects was more sentimental than scientific. The slender data that have reached us through them are of the vaguest character, and their crude speculations are entirely devoid of system.

The Chaldeans.—The weight of evidence favors Chaldea as the home of the first students of Astronomy. The risings and settings of the heavenly bodies were observed by them at a very remote period. They early took notice of eclipses, and have left us a catalogue of these phenomena. Ptolemy gives the dates of six of these events taken from this catalogue, the most ancient going back to 721 B.C. These are the earliest reliable observations in existence.

By noticing the recurrence of eclipses the Chaldeans were enabled to discover the lunar period, called by them the "saros." The saros is a cycle of 6,585⅓ days, or 223 lunations, after the lapse of which eclipses of the same magnitude occur. According to Letronne, to the Chaldeans belongs the honor of having invented the Zodiac, at the beginning of the sixth century before our era. They determined the equinoctial and solstitial points, and are the authors of the duodecimal division of the day. The clepsydra as a time-piece, the gnomon for fixing the solstices, and a hemispherical dial for marking the positions of the sun, were in use among them. The Chaldeans also determined the length of the tropical year to within less than half a minute of its true value.

The Hindoos.—Extravagant claims of a wonderful antiquity have been made respecting the astronomical attainments of this people. Among their records is a statement of a conjunction of the sun, moon, and planets observed in 3102 B.C., and their planetary tables are alleged to be five or six thousand years old. These tables, however, are not grounded upon any true observations, because the conjunctions which they suppose could not possibly have taken place.

Scientific men have proven that this conjunction of all the planets was learned, not from any actual record of it, but by calculating back the position of the planets. The elements of their tables were taken from the Greeks and Arabs, as the tables themselves are a mean between those of Ptolemy and Albategnius, the Arabian.

The Hindoos had a very fertile imagination, and a fondness for round numbers. For instance, a record of theirs, called the "Surya Siddhanta," which they dated over a million of years back, Bentley brought down by his computations to about the tenth century of our era. Schaubach asserts that the astronomical knowledge of the Hindoos has been drawn from the Arabs, and is consequently modern. Laplace says: "The origin of Astronomy in Persia and India is lost, as among all other nations, in the darkness of their ancient history. The Indian tables suppose a very advanced state of

Astronomy; but there is every reason to believe that they can claim no very high antiquity."

The Chinese.—The annals of China mention a conjunction of the planets Mercury, Mars, Jupiter, and Saturn as occurring a century before the Flood. Not only is this a legend, but there is the very highest authority for saying that no truthful records of the Chinese can claim an antiquity greater than that of the foundation of Rome. Among the eclipses reported by the Chinese is that of a very ancient one, occurring October 13, 2127 B.C., or about 217 years after the Flood. All their reported eclipses have been recalculated, and but a single one before Ptolemy's time could be verified.

It seems that the Chinese divided the year into 365¼ days and had an early knowledge of the Luni-solar, or Metonic, Cycle of nineteen years.

Montucla allows that the Chinese discovered the equation of the moon's evection and the proper motion of the fixed stars (precession) in the third century of our era. But the Greeks made these same discoveries five hundred years earlier.

The Chinese have a legend about the tragic death of two of their astronomers, Hi and Ho. They were astronomers to the emperor, and it was their duty to give timely warning of the approach of eclipses, that the proper religious rites which such occasions demanded might be duly performed. Hi and Ho gave themselves up to the too frequent use of wine, and neglect of duty followed. They failed to proclaim the coming of an eclipse, and accordingly, the devotional ceremonies being omitted, China was exposed to the anger of the gods. Not only is this a fiction, but during the ten succeeding centuries not a single astronomical fact is found in Chinese records. The truth of the matter is, that the Astronomy of the Chinese has never advanced beyond a very rude and imperfect condition.

The Egyptians.—Piazzi Smyth claims that the astronomic knowledge of the Egyptians reaches a high antiquity. He points to the pyramids as proof of this. He says that the great pyramid was built at the time when the star α Draconis would be visible through its inclined passage. This would bring its building to 2170 B.C. The weight of scientific authority laughs at this view of Mr. Smyth. The inscriptions on these tombs of Egypt's ancient kings show that they were intended solely for necrologic purposes.

During Napoleon's expedition into Egypt a circumstance occurred that gave that country for a short time the reputation of extraordinary astronomic antiquity. There were found in an ancient temple at Denderah two curiously painted bands containing the signs of the zodiac. They were called the Zodiacs of Denderah. One of these zodiacs was painted in the portico, and the other on the ceiling of an upper chamber of the temple. Two other zodiacs were found in Esneh; one painted in a small-sized temple, the other in a larger one. These were known as the Zodiacs of Esneh.

From a superficial examination of these zodiacs it was concluded that they were executed by some ancient Egyptian, and as the zodiacs were supposed to show the appearance of the heavens at the time of their execution, it signified a fabulous antiquity. Upon a closer and more scientific scrutiny, however, it was disclosed that the zodiacs were of modern date and astrologic character, and belonged to the period when the astrology of Rome was introduced into Egypt.

Egypt was noted for its knowledge of many of the sciences before their cultivation in Greece, and many Greek philosophers, led by the example of Pythagoras, travelled through it to gather wisdom. But Astronomy was not one of its flourishing sciences. It is said that Thales taught the Egyptians the method of calculating the height of the pyramids from the measurement of their shadows, and that they informed Herodotus that the sun, on at least two occasions, was seen to rise in the west. From this it is natural to conclude that their astronomic views were not only very limited, but at times absurd.

The Grecians.—With Greece began the real progress of Astronomy. Thales (636 B.C.), of Miletus, Ionia, was the founder of Greek Astronomy. He is said to have computed the sun's orbit, and fixed the year's length at 365 days. He taught that the earth is a globe, and divided it into five zones. By his knowledge of the saros of the Chaldeans, he could in a vague way forecast eclipses. He held that the stars are composed of fire, and that the earth is the centre of the universe.

Anaximander (610 B.C.), of Miletus, Ionia, a pupil of Thales, taught, it is said, that the moon shines by reflected light, and that the earth turns on its axis. He made calculations on the size and distances of the heavenly bodies. He computed, for instance, that the sun is twenty-eight times larger than the earth. According to Pliny, Anaximander was the first to teach the obliquity of the sun's path.

Anaxagoras (500 B.C.), of Clazomenæ, Ionia, gave a correct explanation of lunar and solar eclipses, and conjectured that the moon had hills and valleys similar to those of the earth.

Pythagoras (580 B.C.), of Samos, taught that the distances between the planets corresponded to the intervals of the scale in music, and is the author of the "music of the spheres." He was the first to point out that Venus is both morning and evening star, and first proposed the heliocentric theory, or that the sun is the centre of the planetary system, the earth revolving around it. With him, however, it was the merest hypothesis, and he advanced no proofs to sustain it. He was pre-eminently a dreamer, and this was regarded as one of his dreams.

Meton (432 B.C.), of Athens, was the inventor of the Luni-solar or Metonic cycle of nineteen years, or two hundred and thirty-five lunations. After the lapse of nineteen years, the new moons very nearly fall on the same days of the year, and eclipses recur in the same order relatively to magnitude.

Calippus (370 B.C.), of Cyzicus, was enabled, by the observation of a lunar eclipse, to detect an error of about a quarter of a day in the cycle of Meton. He proposed to eliminate this error by quadrupling the Metonic cycle and subtracting one day. His cycle of seventy-six years minus a day is called the Calippic cycle, and was adopted in 330 B.C.

Eudoxus (366 B.C.), of Cnidus, was the inventor of the theory of Crystalline spheres, or that the heavenly bodies are set in concentric transparent spheres, revolving at different distances from the earth. He made the earth the immovable centre of the celestial motions, and fixed the length of the year at 365¼ days.

Alexandrian School.—Alexandria, founded by Alexander the Great (332 B.C.), near the Canopic mouth of the Nile, the Greek capital of Egypt, was for about four centuries the centre of science in the ancient world. Here the culture of the physical sciences reached a greater height than anywhere else in antiquity. Its astronomers devoted themselves strictly to the work of observation. Indeed, all the Greek observations of any value begin with the Alexandrian school.

Aristyllus and Timocharis, the earliest Alexandrian astronomers, observed the places of the planets and fixed stars, and determined the times of the solstices (295–269 B.C.)

Eratosthenes (276 B.C.) attempted the measurement of the earth's magnitude by the very method used at present, by measuring the length of a degree of latitude, and computed with fair accuracy the obliquity of the sun's path.

Aristarchus (281–264 B.C.), of Samos, endeavored to estimate the relative distances of the sun and moon through means of the angle which they subtend at the observer's eye when the moon's face is a perfect semicircle. The want of proper instruments and the impossibility of knowing when the moon's face is precisely half-enlightened rendered his method valueless. He estimated the sun's distance at eighteen times the moon's, when in reality it is four hundred times. Humboldt regards him as the pioneer of the Copernican theory, as he was said to have regarded the sun as the centre of the planetary motions. But if he ever held this view, it was in the same sense as Pythagoras, simply as a hypothesis.

Hipparchus, of Nicæa, Bithynia, who flourished in the middle of the second century B.C., was the founder of scientific Astronomy. He was the greatest observer of antiquity, if indeed not the greatest that ever lived.

According to the ancient system of the world, all the heavenly bodies move in a circle and at a uniform rate. The planets, however, appeared occasionally to deviate from this doctrine. They were perceived sometimes to be stationary, sometimes to move on directly, and again to even retrograde. To reconcile the actual with the theoretic movements, it was necessary to introduce the epicycle. Accordingly, the planets were represented as moving in circles around fictitious centres, and these centres again around the earth. While a planet was moving in a small circle, the centre of that small circle was describing a larger circle about the earth. The larger circle was called the deferent, and the smaller, which it carried, was called the epicycle. Thus the motions of the planets about the earth were thought to be similar to what the motion of the moon about the sun really is.

It was also found necessary to imagine eccentrics, to explain certain irregularities noticed in the motions of the sun and moon. Besides moving circularly and uniformly, the heavenly bodies were supposed to move around the earth as a fixed centre. The sun, however, was perceived to move more rapidly in some parts of its orbit than in other parts. This could not be if its motion were uniform and the earth the centre of this motion. In order to account for this want of regularity in the actually witnessed movements of the sun, the ancients took the earth away from the centre of the sun's supposed orbit. This hypothetical orbit of the sun was called the "Eccentric," because its centre did not coincide with the earth's centre. It was also found necessary to give the moon an eccentric.

Hipparchus was the real discoverer and establisher of the Theory of Epicycles and Eccentrics, on the principle that "he only discovers who proves"; for he demonstrated their value and necessity in accounting for the motions of the heavenly bodies.

On this doctrine of epicycles and eccentrics Hipparchus constructed solar and lunar tables, by means of which the places of the sun or moon, with respect to the fixed stars, could be correctly found at any time. These tables enabled astronomers to calculate solar and lunar eclipses. This was a severe test of their accuracy, for very minute changes in the apparent place of the sun or moon would entirely alter the features of the eclipse.

These tables have proved their soundness by creditably bearing this test for centuries. Hipparchus was the discoverer of the precession of the equinoxes, or slow motion of the stars away from the equinox, occasioned by a slight swaying movement of the pole. He was led to this discovery by comparing his own observations of the fixed stars with those of Aristyllus and Timocharis. Hipparchus made a very reliable catalogue of 1,081 stars.

Ancient writers have spoken of the great Bithynian with highest admiration. The moderns have praised him with equal fervor, and even the severe Delambre says: "In Hipparchus we find one of the most extraordinary men of antiquity; the very greatest, in the sciences which require a combination of observation with geometry." The works of Hipparchus are lost, and he is known only through his successor, Ptolemy.

Ptolemy, who flourished in Alexandria about 139 A.D., is the only authority in existence on ancient Astronomy, and on this account has given his name to the old system of the world. His great work, the *Almagest*, was the standard text-book on Astronomy for fourteen centuries. He invented a Planetary Theory, to account for the motions of the planets, and also discovered the Moon's Evection, or swaying. Ptolemy was the last of the great observers of Alexandria.

Arabians.—The culture of Astronomy passed from Alexandria into Arabia. Arabian Astronomy began about 762 A.D., and flourished during four centuries.

The Arabians, though careful and assiduous observers, added but little to the growth of the science. They followed too reverently the methods of their Greek masters. Their observations are valuable, because they were made with more skill and better instruments than those of the Greeks. It may be, too, that the deep azure of Arabia's sky and the dryness of its atmosphere enhanced their precision. They obtained a truer value for the obliquity of the sun's path and the inclination of the moon's orbit.

Albategnius (880 A.D.) was the greatest of the Arabian observers. He published tables of the motions of the sun, moon, and planets, which were improvements on those of Hipparchus and Ptolemy.

Ebn Junis (1000 A.D.), another distinguished Arabian astronomer, also published tables of the sun, moon, and planets, which were called the "Hakemite Tables," in honor of the reigning caliph, Hakem. Ebn-Junis recognized the perturbations of the orbits of Jupiter and Saturn.

A number of other Arabians gave their names to tables of the motions of the heavenly bodies.

The Arabian astronomers made praiseworthy efforts to rectify the older tables, by a comparison with the heavens.

Some Arabic terms are still retained in text-books of the science, as zenith and nadir, azimuth circles and almanac; also such star names as Aldebaran, Rigel, and Fomalhaut.

Copernican System.—The onward march of Astronomy reached Europe in 1230 A.D., when the *Almagest* was translated under Frederick II., of Germany. And in 1252 A.D. astronomical tables were formed at the instance of Alfonso X., of Castile. Nicholas of Cusa, almost a hundred years before Copernicus, ascribed to the earth both rotation on its axis and translation in space. Two distinguished European astronomers, followers of Ptolemy, George Purbach and Regiomontanus, were the immediate predecessors of Copernicus.

We now reach Copernicus (1473–1543), who gave his immortal name to the modern system of the world. He was a native of Thorn, in Prussia, and having distinguished himself in mathematics while a pupil of the University of Cracow, went, at the age of twenty-five, to Rome to study Astronomy under the renowned Regiomontanus. While in Rome he received holy orders, and going back to his native land, was given the poor canonry of Frauenburg, near the mouth of the Vistula. He spent nearly forty years in assiduously observing the heavens and meditating upon its mechanism.

He was a thorough astronomer, and studied nature deeply. He tells us himself that he was first led to suspect the Ptolemaic system by its striking want of simplicity and symmetry. The eccentrics and epicycles had so grown in number as to become enormously cumbersome. The more he studied nature, the more he became convinced of the simplicity and symmetry of her conduct. Driven from the Ptolemaic system, which made the earth the centre of motion, he tried the heliocentric, which places the sun at the centre of the celestial movements. Having chosen his hypothesis, he fervently devoted his great energies to the task of its establishment.

He soon satisfactorily accounted for the diurnal revolutions of the sun, moon, and stars, the slow progress of the planets through the signs of the Zodiac, and the numerous irregularities to which the planetary motions are subject. He studied long and patiently apparent motion in all its aspects. When rapidly moving by a headland on a sailing vessel we lose the consciousness of our own motion, and see the shore recede. Trees and other objects appear to glide by us when riding swiftly past them. So the actual revolution of the earth on its axis in twenty-four hours from west to east produces the apparent diurnal movements of the sun, moon, and stars from east to west. The leading tenets of the Copernican doctrine are: 1. The earth revolves on its axis, daily producing an apparent revolution of the heavens. 2. The sun is the centre around which the earth and planets revolve from west to east. He clearly explained how the apparent annual revolution of the sun among the stars could be produced by the annual revolution of the earth around the sun.

Copernicus, however, continued to believe with the ancients in the circular motion of the heavenly bodies, and so was obliged to retain a portion of their epicycles and eccentrics. He had but very primitive instruments to aid him in his grand revolution, and so did not add much to observational astronomy. His greatest glory is to have clearly pointed out the right path, though he himself did not travel far along it. His great work, *On the Revolutions of the Heavenly Bodies*, was published at the earnest entreaty of his friend, Cardinal Schomberg, and the first printed copy was put in his hands a few days before his death.

Tycho Brahé (1546–1601), of Knudsthorp, Denmark, was one of the most indefatigable observers that ever lived. His observations were both abundant and accurate, and it was mainly through the means of his accurate work that Kepler was enabled to discover his great laws.

Tycho did not give his assent to the Copernican doctrine, but originated a system of his own. He maintained that the earth is the centre of the universe, around which the whole host of heaven make a diurnal revolution; that the moon revolves about the earth as the centre of her motions; that the planetary bodies revolve around the sun as the centre of their motions, and that the sun, carrying with him the planets, travels annually around the earth.

Among his many discoveries were those of the variation and annual equation of the moon. He made the first table of refractions, and compiled a catalogue of 777 fixed stars, a more perfect catalogue than any previous one. He also left some valuable observations of comets. To aid him in his astronomic labors he had a magnificent observatory and many beautiful and rare instruments, the workmanship of his own ingenuity. He has been called the founder of modern astronomical calculations.

Kepler (1571–1630), of Magstadt, Würtemberg, discovered the three remarkable laws bearing his name that govern the motions of the heavenly bodies. He assisted Tycho Brahé in his observations, and was an enthusiastic advocate of the Copernican theory. It was his efforts to reconcile the various positions of the planet Mars, as observed by Tycho Brahé, with the Copernican doctrine of circular motion around the sun that led Kepler to the discovery of his laws. The first law is, that the planets move in ellipses, with the sun as one of the foci; the second, that a line joining the planet and sun sweeps over equal areas in equal times; and the third, that the square of the times of revolution of the planets is proportioned to the cube of their mean distances from the sun.

Kepler was a man of the most indomitable perseverance. The discovery of his third law took twenty-two years of the most vigorous application. He wished to establish some relationship between the time of revolution and the mean distance of the planet from the sun. He worked on the problem for twenty-two years before solving it, and although he failed again and again in its solution, still he persevered. The glory of his discoveries is much enhanced when we consider the difficulties he had to contend with. Modern Astronomy was in its infancy, the instrumental aids were scanty, and the reliable facts meagre; add to this that his life was one of peculiar sadness and singular hardships, and an everlasting struggle with poverty. Kepler freed the Copernican system of eccentrics and epicycles. He established the law of the diminution of light in proportion to the inverse square of its distance. He calculated the times of the transits of Mercury and Venus across the sun's disc. He affirmed that bodies attract in proportion to their mass. Both Kepler and Copernicus had a notion of the law of gravitation. John Kepler was one of the greatest astronomers of all ages.

Galileo (1564–1642), of Pisa, the discoverer of "the three laws of motion," and called the father of experimental science, was the first to apply the telescope to the study of the heavens. His grand discoveries rapidly dissipated all doubt regarding the truth of the Copernican system.

The telescope enabled him to see, in quick succession, the inequalities of the moon's surface, the spots on the sun, the satellites of Jupiter, the appendages of Saturn, and the phases of Venus. The discovery of the Jovian system to be a perfect miniature of the Solar system, and that of the phases of Venus showing it to be an interior planet, may be said to have finally established the Copernican doctrine.

Newton (1642–1727), Woolsthorpe, Lincolnshire, discovered the great law of universal gravitation: that the force of gravity is proportioned to the quantity of matter and inversely as the square of the distance. Jean Picard's accurate measure of the earth's radius, in 1670, furnished Newton the means of establishing this great fundamental truth.

Mathematics and mechanics now commenced a wonderful growth, and Astronomy, with their aid, made rapid strides in progress.

Scheiner, Huyghens, Leibnitz, Dominicus Cassini, Halley, Bradley, Lalande, Lagrange, Delambre, Laplace, and Herschel greatly improved the science of Astronomy by their valuable researches.

On the first evening of the nineteenth century Piazzi discovered the first of the Asteroids, or minor planets. This opened a new field of discovery, which was entered with avidity. Planetoid after planetoid was found in rapid succession, until 281 of these small bodies are now known to Astronomy, revolving in the great void between Mars and Jupiter.

Leverrier (1811–1877), of Saint-Lô, performed the greatest astronomic feat of the century. He calculated the mass and orbit of the planet Neptune from the perturbations it occasions in the path of the planet Uranus. So precise were his figures that when the telescope was turned, on the 23d of September, 1847, to the place in the heavens indicated by Leverrier, the planet was found within one degree of the computed point. This brilliant achievement demonstrated the high perfection to which the science had reached. Leverrier's theory and tables of each one of the major planets is one of the greatest works ever accomplished by an astronomer, and occupied thirty-four years of incessant labor.

In recent years America has given to Astronomy some of its brightest names. The recent progress of the science has been materially assisted by the contributions of Professor Holden; S. W. Burnham, the great double-stars resolver; Asaph Hall's discovery of the satellites of Mars and his star parallaxes; Kirkwood's lucid theory of comets and meteors and law of the distribution of the asteroids; the elder Bond's discovery of Saturn's dusky ring; the labors of the younger Bond and Peirce on the nature of the structure of Saturn's rings; and the valuable researches on the Corona, the distance of the sun, the lunar theory, and formation of the planets by the Nestor of American astronomers, Professor Simon Newcomb.

The momentous discovery of Spectrum Analysis has created a "New Astronomy," grown up beside the Old. This New Astronomy studies the sun, moon, and stars for what they are in themselves and in their relation to us. It studies their chemistry or physical constitution, and hence it is also called Solar Physics or Celestial Physics. Spectrum analysis is a mode of distinguishing the various species of matter by the kind of light proceeding from each. The most obvious distinction between one kind of light and another resides in the color. In the refracting prism or spectroscope there is a scale of color. Substances have their characteristic place in this scale. The spectroscope is a wonderful instrument in the hands of the astronomer. It recognizes the presence and condition of matter in the face of almost infinite minuteness and almost infinite distance. It will detect the one-eighteen-millionth of a grain of sodium in the flame of a spirit-lamp, and reliably indicate the material composition of the sun or even of the faintest star. The spectroscope shows that many of our familiar elements exist in the sun in the vaporous state; that the stars are incandescent globes enwreathed with glowing vapor containing some of our known elementary substances; that some of the nebulæ are resolvable into stars, and some are glowing gas mostly composed of hydrogen and nitrogen. The spectroscope also gives an approximate measure of the motion of the stars.

Among the great workers in the field of the New Astronomy distinguished places are due to Fraunhofer, Kirchhoff, Huggins, Secchi, Respighi, Lockyer, Zöllner, Janssen, and our own illustrious three—Draper, Young, and Langley.

Celestial Photography is a great aid to the astronomer of to-day, and has made wonderful progress within a very few years. The chemical plate is sensitive to rays which are incapable of affecting vision, and by long exposure can accumulate impressions almost indefinitely. Faint objects may thus be photographed which the telescope could never reveal. Photography also registers planetary, solar, and stellar phenomena independent of the source of error of ordinary observation.

Stellar Photometry, which treats of the measurement of the intensity of star-light, has reached such excellence that it is now cultivated as a separate branch of Astronomy. Professor Pickering has done much valuable work in this field, and has already constructed a photometric catalogue giving a careful measurement of the brightness of 4,260 stars.

Electricity has found its way into the observatory, and has been of great advantage in many ways to the observer. In Astronomy it is of the highest importance to be able to measure exactly extremely small intervals of time. The revolving cylinder and electric marking apparatus divide a second into a thousand equal parts.

CHAPTER II.

THE DIVISION OF TIME AND THE CALENDAR.

THE DIVISION OF TIME.

One of the earliest purposes of Astronomy was to afford a means of measuring time. The astronomical divisions of time are the day, the month, and the year. Indeed, these three divisions have been in all ages the fundamental units of time, the first being measured by the revolution of the earth on its axis, the second by that of the moon around the earth, and the third by that of the earth around the sun.

The day is the most striking and best marked division of time. Man in a very primitive condition must have been able to form a conception of the day as a measure of time. The recurrence of light and darkness, warmth and cold, noise and silence, the rising and setting of the sun at almost equal intervals, must have arrested the attention of the rudest people. And the intervals of repetition are so short as to be capable of being grasped by the weakest memory. The alternation of day and night, occurring with such uniformity, furnished in all ages the most definite unit of time.

There are two kinds of days, a sidereal and a solar day. A sidereal day is the length of time it takes the earth to turn on its axis relatively to a fixed star. A solar day is the time of revolution relatively to the sun, and is the interval of time which elapses between two successive passages of the sun over the meridian. The solar is nearly four minutes longer than the sidereal day. The difference is occasioned by the earth's motion of translation around the sun. Whilst the earth is turning on its axis, it is at the same time pushing on in its orbit at the rate of nineteen miles a second. If the earth had remained fixed in space, the sun and stars would reappear at the same time in the meridian, the sidereal would have been of the same length as the solar day. But the earth is not fixed, it has travelled onward to another point. The star, because it is situated at an almost infinite distance, is again found, after a complete rotation, in the meridian; but the sun, its distance being appreciable, is thrown a little out of position, and the earth must turn through a space of one degree of arc, or four minutes of time, to bring the sun to the meridian.

Another explanation is this: The real westward motion of translation of the earth in its orbit gives the sun an apparent eastward motion among the stars. In one year, or 365¼ days, the sun apparently travels eastward around the whole heavens, or over 360 degrees of an arc. It thus moves eastwardly nearly one degree a day. While, therefore, the earth is turning on its axis, the sun is moving in the same direction, so that when we have come round under the same celestial meridian from which we started, we do not find the sun there, but he has moved eastward nearly a degree, and the earth must perform so much more than one complete revolution before we come under the sun again. Now, since we move, in the diurnal revolution, fifteen degrees in sixty minutes, we must pass over one degree in four minutes. It takes, therefore, four minutes for us to catch up with the sun after we have made one whole revolution. Hence the solar day is about four minutes longer than the sidereal day.

The earth's path around the sun is not a circle; it is an ellipse, and so the real motion of the earth in its orbit, or the apparent motion of the sun in its path, is not uniform. Again, the variable inclination of the sun's path to the equator is another cause of irregularity in the sun's apparent motion. Consequently, owing to these causes, the solar days do not always differ from the sidereal days by these four minutes. The daily time by the sun is called apparent time. Mean time is the average length of all the solar days throughout the year. The mean or average day is the civil day, and consists of twenty-four hours, beginning at midnight, when the sun is on the lower meridian.

The astronomical day is the apparent solar day counted through the whole twenty-four hours, and begins at noon. Astronomers make most of their observations on the meridian, and are mostly looking towards the south; and left with them means east, and right west. Geographers, on the other hand, regard the right as east and the left as west, because formerly they were more familiar with the northern than the southern hemisphere, and were thought to look towards the north.

Civil or mean solar time is the time kept by clocks. This mean solar time, as already mentioned, differs continually from apparent time, or the time marked by the sun. The sun is sometimes fast and sometimes slow. The difference between mean time and apparent time is called the equation of time. Almanacs contain the equation of time for every day in the year. As no clock, however perfectly constructed, can be relied upon to run to true mean time, or to any exact definite rate, therefore clocks must be frequently rectified by the sun. We can observe the apparent time by the transit instrument, and then, by the application of the equation of time, we determine the true mean time. When the sun is fast, it comes to the meridian before twelve o'clock, true mean time; and when slow, it comes to the meridian later than twelve o'clock. The amount, fast or slow, for each day is found in the table of the equation of time. When the sun is fast we must subtract the equation of time from apparent time to obtain mean time; and conversely when the sun is slow.

It happens, however, four times in the year that the mean and apparent times are equal to each other; namely, April the 15th, June the 16th, September the 1st, and December the 24th. Their greatest difference is on the 3d of November, when the apparent is 16 minutes and 17 seconds greater than the mean time.

Mean time is so measured that the hours and days shall always be of the same length, and shall, on the average, be as much ahead of the sun as behind it. Corrections are constantly made at the chief observatories, and time-signals wired at fixed hours to all points throughout the country.

Next to the day the most natural division of time is the year. The notion of a year arose, in the same manner as that of a day, from the recurrence of certain facts after certain intervals. Indeed, in all parts of the world the yearly cycle of changes has been singled out from all others, and designated by a peculiar name. The Latin term for year signifies a ring, the Greek implies something which returns into itself, and our own word year is derived from the Swedish of ring.

A year is the period of the revolution of the earth around the sun. The sidereal year is the period required by the sun to move from a given star back to the same star. It consists of 365 days, 6 hours, 9 minutes, 9.6 seconds. The tropical year is the time which elapses from the sun's appearance on one of the tropics to its return to the same, and has an average length of 365 days, 5 hours, 48 minutes, 49.7 seconds. The tropical year being the one commonly applied to the measure of time, is also called the civil year. Owing to the precession of the equinoxes, or the retrogradation of the equator on the ecliptic, the tropical is less than the sidereal year by about 20m. 20s.

The most ancient nations determined the number of days in the year by means of the stylus or perpendicular rod, which casts its shadow along a level plane bearing a meridian line. The shadow was seen to be shortest at the summer solstice; and the number of days that elapsed until the shadow was again the shortest was found to be 365; and this period was adopted for the civil year. But the real length of the year is very nearly 365 days and a quarter. If a year of 365 days were used, in four years the year would begin a day too soon. At the end of four more years it would begin two days too soon; and in the progress of time the civil year would be found not to coincide with the year of the seasons, and thus all dates would be thrown into confusion.

The Julian year, which we now use, consists of 365¼ days, and takes its name from its adopter, Julius Cæsar.

The Egyptians knowingly permitted their civil year to wander, as they wished their religious festivals to go through all the seasons of the year. In 1,461 years the festivals would make a circuit of the seasons; for 1,460 years of 365¼ days are equal to 1,461 years of 365 days. This period of 1,461 years is called the Sothic Period, from Sothis, the Egyptian name of the Dog-star.

The Egyptians corrected their time by the rising of Sirius, or the Dog-star.

The number of days in a year is too great to be easily remembered, and so a middle measure between the day and year was desired. The phases of the moon suggested such a measure. It was noticed that new moons succeeded one another after average intervals of 29½ days. Thus the age of the moon furnished a convenient measure of time. The moon travels from one point in the heavens back to the very same position in 29½ days. These 29½ days constitute a lunation or lunar month. The actual length of a lunation is 29 days, 12 hours, 44 minutes, and 3 seconds. In that time the moon returns to occupy the same position with respect to the sun and earth. But the moon makes a sidereal revolution of its orbit, or moves from a fixed star back to the same fixed star, in 27 days, 7 hours, 43 minutes, and 11½ seconds. This difference of more than two days is caused by the motion of the earth in its orbit. While the moon is going around her orbit the earth has travelled quite a distance in her own orbit, and it takes the moon a little over two days to pull up this difference.

The Greeks and other ancient nations made the year depend on the course of the moon. They supposed that twelve lunations were equal to one revolution of the sun. Consequently their year numbered 354 days, being 12 months of alternately 29 and 30 days each. But this year differed from the year that governed the seasons by more than 11 days. This difference between the year of the seasons and the civil year would gradually widen and be a source of much confusion. Efforts were made to rectify the matter by introducing a number of days into the civil year, to make it agree with the course of the sun. But the additions, or intercalations, as they were called, were often omitted and frequently made at pleasure, and so the year was sometimes long and sometimes short.

The difficulty of making any specific number of lunar months correspond with the sun's course was so great that the lunar month was generally abandoned, except by those people whose religious ceremonies depended on the time of new moon. Among those who abandoned lunar months the year has been divided into twelve months of slightly different lengths.

The Greeks, who retained the lunar months on account of their religious rites, had great difficulty with their dates, until the Athenian mathematician, Meton, in 432 B.C., discovered the Metonic Cycle of nineteen years, which is so correct and convenient that it is in use to this day. Meton discovered that 19 years are almost equal to 235 lunations. 235 lunations are greater than 19 true tropical years by 2 hours and 4 minutes. And 19 Julian years are greater than 19 true tropical years by 3 hours and 33 minutes. Hence, if the 19 years be divided into 235 months, so as to agree with the changes of the moon, at the end of that period the same succession may begin again with great exactness.

Calippus, in 330 B.C., by observing an eclipse of the moon, discovered the error of the Metonic Cycle, and slightly corrected it by leaving out a day at the end of four of Meton's cycles. Four Metonic cycles are equal to 76 years, and these constitute the Calippic period.

The week, as a division of time, has come to us from the Mosaic dispensation. The Jews, however, had no special name for the single days, but counted their number from the previous Sabbath. Thus Sunday was the first and Friday the sixth day of the week. Saturday, Sunday, and Monday derive their names obviously from Saturn, the Sun, and the Moon. Tuesday, Wednesday, Thursday, and Friday borrow their names from the Saxon of Mars, Mercury, Jupiter, and Venus.

THE CALENDAR.

The arrangement of the divisions of time with us, or our calendar, has come from ancient Rome. In the reign of Numa the Roman civil year consisted of 355 days. This king, in order to compensate for the shortage in the civil reckoning, ordered the insertion, after certain intervals, of an intercalary addition to the year. This correction was frequently omitted for political reasons, and, in the consulate of Julius Cæsar, the direst confusion had crept into the Roman dates. The civil year had grown 90 days too long. Cæsar called upon Sosigenes, an astronomer of the famous school of Alexandria, to assist him in the formation of a calendar. By the advice of the latter, the new Roman calendar was ordered entirely by the motion of the sun. The year 46 B.C. was made to consist of 455 days. This was done in order to throw away the 90 days that had crept into the civil year through the errors of the old system of reckoning. The year 45 B.C. was the first regular year under the new calendar, and began on the 1st of January, it being the day of the new moon immediately following the winter solstice. The Romans were the first to adopt the 1st day of January as the first of the year.

According to the Julian calendar the year was to consist of 365¼ days, so contrived that the year would ordinarily consist of 365 days, and every fourth year would be bissextile, or leap-year, consisting of 366 days. It was called bissextile because the 6th of March was doubled. The Julian rule was, however, an over-correction. It made the year consist of 365 days and 6 hours, when in reality the length of the true tropical year is 365 days, 5 hours, 48 minutes, and 50 seconds. The Julian year is too long by 11 minutes and 10 seconds, and would occasion an error of a week in about a thousand years. The error reached ten days in the sixteenth century, and caused some confusion in regard to the time of celebrating Easter.

Pope Gregory XIII. rectified the matter by reforming the calendar. He ordered that the 5th of October, 1582, should be reckoned the 15th of October. And in order to avoid future confusion, he ordained that every hundredth year should not be counted a leap-year, excepting every four-hundredth, beginning with the year 2000.

The Gregorian rule is as follows: The years are numbered from the Birth of Christ. Every year whose number is not divisible by 4 without a remainder, consists of 365 days; every year which is divisible by 4, but not by a hundred, consists of 366 days; every year divisible by 100, but not by 400, again of 365 days; and every year divisible by 400, again of 366 days.

The actual value of the solar year, reduced to a decimal fraction, is 365.24224; and of the Gregorian 365.2425, so that the error of the Gregorian rule on ten thousand tropical years is 2.6 days. This is an error of less than a day in three thousand years. The rule is sufficiently accurate for all civil reckoning.

In order to form a perfect and convenient calendar, the units of measurement should be invariable and commensurable. Nature has forced upon us as units of time-measure the solar day and tropical year. The most unchangeable thing in nature is the length of the mean solar day, which may indeed be said to be absolutely invariable, as it has not varied the hundredth part of a second within historic times. The tropical year, owing to a retrogradation of the ecliptic on the planetary orbits, has shortened 4.21 seconds since the time of Hipparchus. Nevertheless, it is sufficiently invariable for all purposes, and particularly as the day is, in effect, the real standard unit. All the troubles of the calendar, then, arose from the incommensurability of the tropical year and the solar day.

The Golden Number.—Meton discovered that 235 lunations brought the moon back to where she was 19 years before. Thus, new moon occurred on new year's day in 1861; it did not occur on the same day until after a lapse of 19 years, or until 1880; and it will fall on this same day every 19 years for about 400 years. This period of 19 years is hence known as the Metonic or Lunar cycle. The Golden Number is the number of this cycle corresponding to the current year. The golden numbers range from 1 to 19. The number of each year in the Metonic cycle was formerly ordered by the Greeks to be engraved in letters of gold on marble pillars, and hence the origin of the name.

Under the Gregorian rule the golden number is reckoned from the year 1 B.C. In that year the new moon came on the 1st of January, and has come on new year's day every 19th year since. To find the golden number for any year, add one to the number of the year, divide the sum by nineteen, and the remainder will be the golden number for that year. If there be no remainder, then nineteen is the golden number of the year, or the last of the cycle.

Epact.—The Epact (derived from a Greek word meaning to bring on or in) is the age of the moon on new year's day. On new year's day, in the year 1 B.C., the calendar year and the lunar year began together. On the next new year's, the lunar year having run out eleven days sooner than the calendar year, the moon was eleven days old, the calendar being (nearly) 365 and the lunar year 354 days. Thus eleven days was the moon's age on new year's day of that year, or that year's epact. In the next year there was a difference of twenty-two days between new moon and new year's day, and so on.

To find the epact for any year, divide the year by nineteen, the Lunar cycle, multiply the remainder by eleven, the excess of the calendar above the lunar year, and divide the product by thirty, the number of days in a mean calendar month; the remainder will be the epact of that year. Or a shorter method is to subtract one from the golden number of the year, multiply the remainder by eleven, divide the product by thirty, and the remainder will be the epact. Should there be no remainder, the age of the moon will be twenty-nine and a half, the number of days in the average lunar month.

To find the date of the January new moon, the epact must be subtracted from 29½ days, the length of a lunation. The dates of the successive new moons, in any year, can be found by adding 29 and 30 days alternately to the date of the January new moon. When we thus have the date of the January new moon for any year, we can easily find the date of any new or full moon throughout that year.

Easter.—Easter is the Sunday following the first full moon after the vernal equinox. This time for the Easter celebration was fixed by the Council of Nice, held in the year 325 A.D. In that year the vernal equinox fell on the 21st of March. In the Gregorian calendar the vernal equinox falls on the 21st of March, and the "full moon" is the 14th day of the calendar moon.

Easter, then, is always the first Sunday after the full moon which happens upon or next after the 21st of March. If the full moon fall on the 21st of March, and this be a Saturday, the next day will be Easter Sunday. If the full moon happen upon a Sunday, Easter Day is the Sunday after. If the full moon fall on the 20th of March, this moon cannot be considered the Paschal moon; the next moon only, which will be on the 18th of April, can be reckoned such. Should this 18th of April be a Sunday, Easter would be the Sunday following, or the 25th of April. Easter, then, can be no later than the 25th of April, nor earlier than the 22d of March. Easter determines the times of all the movable feasts of the Christian Church.

To determine the time of Easter for any year, find, through means of the golden number, the epact, or the moon's age on the new year's day of the year; subtract this from 29½ days to find date of the January new moon; add alternately to this date 29 and 30 days for each moon, until the full moon immediately succeeding March 21 is found; the following Sunday is Easter.

The Solar Cycle.—It is often desirable to know the day of the week on which an event happened, when only the day of the month and year are given. After the lapse of a certain period it is found that the same day of the month recurs to the same day of the week. This period is called the Solar Cycle, and consists of 28 Julian years. If the year consisted of exactly 52 weeks, or 364 days, the day of the week and the day of the month would always correspond; and if Monday were the first day of the year, it would be the first day of every year for all time to come. But the year consists of 365 days, or one day more than 52 weeks. Hence, any day of the month is one day later in the week than the corresponding day of the preceding year. If the year begins on Tuesday, we should complete 52 weeks on Monday, leaving one day, Tuesday, to complete the year, and the following year would begin on Wednesday. So that every day of the week goes back, every year, one day from the date it occupied on the previous year. Leap-year, however, consists of 52 weeks and two days; and all the days of the week in the succeeding year, and from February 29 of leap-year, go back two days. If the year consisted regularly of 365 days, at the end of seven years the days of the month and week would again correspond. Leap-year comes in every fourth year, however, as a disturbing element, and prevents this coincidence of the day of the week and the day of the month after seven years' intervals. We have here intervals of seven years and of four years that must be reconciled. This reconciliation is effected by taking a period corresponding to their common multiple, 28. The coincidence between the days of the week and the days of the month regularly recurs after 28 years. The Solar cycle is arranged so that it takes as its starting point the year 9 B.C., and is thought to have been invented about the time of the Council of Nice (325 A.D.) The leap-years in the Solar cycle are computed according to the Gregorian rule.

Cycle of Indiction.—This is a cycle of 15 years, and owes its origin to the fact that the Roman emperors issued their edicts for the collection of the tribute every fifteen years. It is frequently mentioned in ecclesiastical history, and is reckoned from the 1st of January, 313 A.D.

The Julian Period.—This is a compound cycle, and consists of 7,980 years. It was invented by Joseph Scaliger, and is the least common multiple of the Solar, Lunar, and Indiction cycles. Its purpose is to have some standard epoch to which the chronological reckonings of the different nations may be referred. A hypothetical date, 4713 B.C., is fixed as the period of its commencement. The Julian period for any year is found by adding 4,713 to that year. The Julian period for 1888 is 4,713 plus 1,888, or 6,601. The Solar cycle for any year is found by dividing its Julian period by 28; the remainder is its Solar cycle. When the remainder is 0 the Solar cycle is 28, because it is the last year of the cycle. The Metonic cycle for any year is found by dividing its Julian period by 19; the remainder is its Metonic or Lunar cycle. The Indiction for any year is found by dividing its Julian period by 15; the remainder is its Indiction.

Dominical Letter.—The early Christians introduced the custom of placing the first seven letters of the alphabet, A, B, C, D, E, F, and G, in the order of their succession, against the days of the month. The 1st of January was represented by A, the 2d by B, the 3d by C, and so on to G, when the seven letters began over again, and were repeated through the year in the same order. The letter that falls against the first Sunday in January in any year is called the Sunday or Dominical Letter of the year, and will fall against every Sunday in that year if it be a common year. An exception occurs in leap-years, when February 29 and March 1 are marked by the same letter, so that a change occurs at the beginning of March. In leap-years there will be two dominical letters, that for the last ten months of the year being the one next preceding the letter for January and February. Any day of a past year occurred one day earlier in the week for every year that has elapsed, and, in addition, one day earlier for every 29th of February that has intervened.

The dominical letter, being known for any one year, can be found for any other by simply remembering that an ordinary year is 52 weeks and one day, a leap-year 52 weeks and two days, so that the dominical letter will go back from G towards A one letter for a common year and two letters for a leap-year. The Solar cycle brings back the days of the week to the very same days of the month. Hence the days of the week fall upon the same days in the same month every 28th year. So that every 28th year has the same dominical letter.

To find the dominical letter for any year of the nineteenth century, take the number of the year and add one quarter of itself, neglecting fractions, and divide the sum by seven; then subtract the remainder from 8, or, if it is 0, from 1, and the new remainder will be the number of the dominical letter in the alphabet. If it be a leap-year, the dominical letter thus obtained belongs to the time after February 29, and for the preceding two months the dominical letter will be the succeeding letter in the alphabet. In computing the dominical letter for other centuries, it must be remembered that, under the Gregorian rule, 1700, 1800, 2100, and so on, are not leap-years.

The new remainder above mentioned will also represent the date of the first Sunday in the January of the year.

CHAPTER III.

THE SPECTROSCOPE.

THE Spectroscope, in producing the science of Solar or Celestial Physics, has in reality given us a New Astronomy. In 1867 Kirchhoff and Bunsen published their researches on Spectrum Analysis, and the birth of the new science is dated from that year. The Old Astronomy dealt principally with the measures of celestial distances and magnitudes. The New Astronomy is a celestial chemistry, and concerns itself with the constitution of the heavenly bodies.

A beam of sunlight is composite, and, though itself colorless, is really a blending together in a certain proportion of all colors. The tiny globes of water suspended in the clouds decompose the sunbeams entering them at certain angles, and produce the many-colored rainbow. These little globes separate the rays one from another by bending them in different degrees as they pass through. A glass prism acts similarly on sunlight, and divides it into red, orange, yellow, green, blue, indigo, and violet.

When a ray of light passes through a glass prism it is bent from its course, and emerges in a direction different from the primitive one. If all the rays were equally bent, the light, although taking a new path, would come out as it went in, and there would be no analysis. But the rays are unequally bent, and, as a result, come out separated. This property of the prism is called refraction. The band of colors spread out on a screen behind the prism by a substance's light is called its spectrum. By the spectrum of any object is, then, meant the combination of colors found in the light which emanates from that object.

The rays of light passing from a rare to a more dense medium are all bent towards the perpendicular. The bending of some of the rays, however, is greater than that of others. The red ray is bent much less than the violet. Red is at one end of the spectrum and violet at the other; and between these a great variety of tints, caused by the interlacing of the so-called primary colors. The red, being bent the least, is said to be the least refrangible. The violet is bent the most, and has the greatest refrangibility. After refraction the sunbeam is no longer white, but a band of many colors all the way from red to violet.

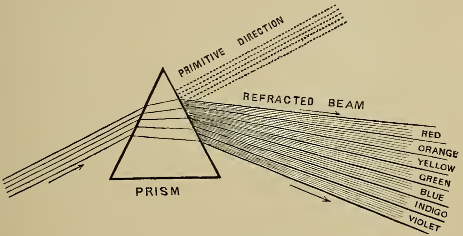

Fig. 2.—Decomposition of Light by Prism.

In this way light from any source whatever can be decomposed into its component parts. The character of the light will make known to us the constitution of the body whence it is emitted. In many cases the color alone of the light will suffice to do this. Thus a well-known splendid red light is characteristic of the metal strontium. Sodium has a yellow light, easily distinguishable. It is seen in the burning of common salt. The brilliant bluish white of the magnesium light is well known.

The Spectroscope is an improvement upon the prism. The Spectroscope consists mainly of a small telescope, called the collimator, to which is attached a prism of flint-glass, and to the prism is attached a second small telescope. The collimator collects the rays from the object to be analyzed; the prism disperses the rays; and the second telescope, being at an angle to the prism corresponding to the angle of the bend given to the rays by the prism, brings the different rays to their proper foci. The collimator carries a slit, to insure the admission of only a narrow beam of the light to be analyzed.

When sunlight passes through the Spectroscope its spectrum is found not to be continuous from end to end, but, on the contrary, broken up or shaded over by a number of dark lines or divisions. These dark lines are a permanent feature of the solar spectrum, and with a strong Spectroscope run up into the thousands. They are of all degrees of distinctness and feebleness.

In the solar spectrum let us take one line, the sodium, or, as it is marked, the D line, for instance. This D line consists in reality of two lines separated by a very small interval, and one of the lines is a little darker than the other. When the sunlight passes through the Spectroscope, among the many dark lines of the solar spectrum the D lines are easily recognized. If, however, the sunlight, before entering the Spectroscope, is first passed through the flame of a spirit-lamp colored with common salt, it will be noticed that these two lines composing the D line will appear suddenly

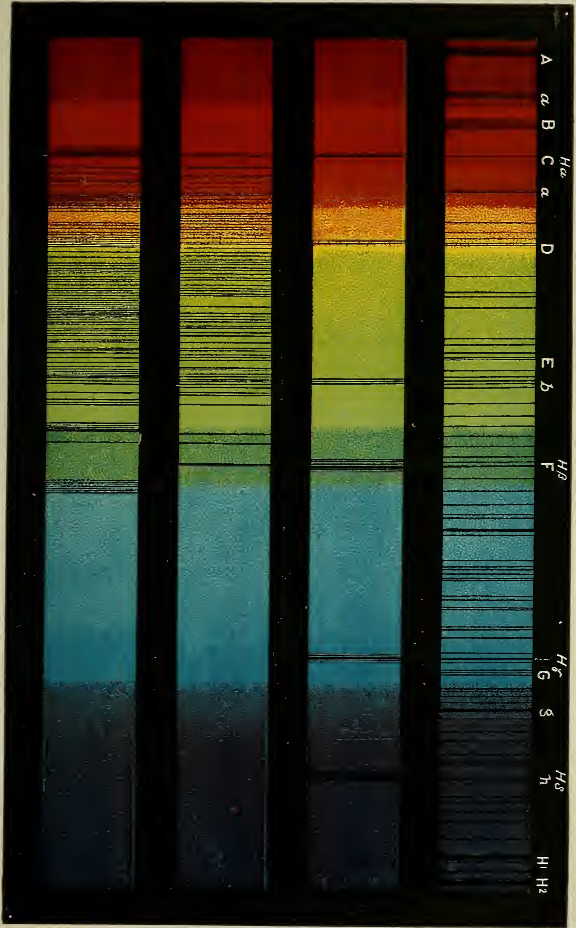

Fig. 3.—SPECTRA OF THE SUN AND STARS.

more vividly black. This is due to the sodium light of salt. If now all light but the sodium light be removed, the prismatic colors will no longer appear. We will find two bright yellow lines in the whole spectrum, filling exactly the places held before by the two dark lines of D. This is really the sodium line. The sodium flame produces two bright yellow lines when its light alone is used; but when the sunlight passes through the sodium flame it eliminates the yellow lines, and produces in their stead black lines. The sodium light intensifies the black lines, because the light of a metal passing again through its own light is absorbed. The sodium light from the sun, in passing through this sodium light of the lamp, is absorbed, and leaves only dark bands. This process is called selective absorption. Here we see the very principle of spectrum analysis. Sodium light passing through heated sodium vapor is absorbed or eliminated, and where its characteristic lines should be seen in the spectrum we find only dark lines.

Kirchhoff, by reversing the spectra of certain substances, discovered that vapors of metals and gases absorb those rays which the same metals and gases themselves emit. The dark lines in the solar spectrum are there because something is at work cutting out those rays of light which are wanting. Around the sun and stars are absorbing atmospheres containing the vapors of certain elements found in the interior of the sun or stars. If sodium is present in the sun and is also present in its atmosphere, instead of finding the lines in the spectrum corresponding to sodium we find dark lines, because the sodium light of the sun's atmosphere absorbed the sodium light from the sun. If iron is present in the sun and present also in its atmosphere, instead of finding the iron lines in the spectrum we see dark lines; and so on of other elements.

If we so employ a prism that while a sunbeam is decomposed by its upper portion a beam proceeding from such a light-source as sodium or other element may be decomposed by its lower one, we will find that when the bright lines of which the spectrum of the metal consists flash before our eyes they will occupy precisely the same positions in the lower spectrum as some of the dark bands do in the upper solar one. So that each element's spectrum, besides its characteristic lines and color, has an established place.

What we can see of the solar spectrum is really but a fraction of the whole. Beyond the red end there are invisible rays of high caloric powers; and beyond the violet there are invisible rays recognized by their chemical effects, as in photography. The invisible rays can be rendered visible by the agency of fluorescent bodies.

Wollaston (1802) was the first to discover that the solar spectrum is not continuous, but crossed by dark bands. These bands were first, however, measured by Fraunhofer (1815), and are therefore usually called Fraunhofer's lines. It was Fraunhofer also that suggested the employment of a telescope to replace the screen. Fraunhofer's telescope multiplied Wollaston's five dark lines into six hundred. Brewster (1832), with a still more perfect contrivance, counted two thousand lines in the solar spectrum. Fraunhofer, using candle, gas, or lime light, perceived no dark lines in their spectra. Brewster was the first to offer an explanation of the presence of the dark lines in the solar spectrum. In passing light through nitrous acid gas he noticed that its spectrum was interrupted by dark divisions.

The application of heat to the gas increased the number of divisions, and at a very high temperature he found this gas opaque to sunlight. Hence he concluded that the presence of the dark bands in the solar spectrum is caused by some medium between us and the sun absorbing certain of the rays. Fraunhofer next made his experiments with common salt in the flame of a spirit-lamp, and saw that sunlight, passing through, darkened the D or sodium lines.

Talbot and Herschel (1826), experimenting with glowing Lithia and other elements, showed that their flames rendered some of the dark bands of the solar spectrum still more vividly dark. They applied this new analysis to the detection of metals in combination, and so began spectrum analysis.

Foucault (1849) by an experiment illustrated the true theory of this new analysis, but failed to generalize the result. Placing salt in the electric arc, he saw the double bright yellow line of sodium. When he passed sunlight through the sodium flame the yellow lines disappeared and the dark lines of D were strengthened.

Professor Stokes (1850) divined the true explanation of Foucault's experiment, his theory being that an absorbing atmosphere of sodium surrounds the sun, the sodium light of the atmosphere absorbing the sodium light of the sun. He neither verified nor published his theory, however, and contented himself with confiding it to a friend.

Balfour Stewart, Angström, and other philosophers, ten years later, seem to have rediscovered this theory of Stokes. Kirchhoff, by reversing the spectra of certain substances, finally established the theory of absorption by a full and satisfactory verification, and in conjunction with Bunsen discovered, through the medium of the Spectroscope, two new metals, Cæsium and Rubidium,

CHAPTER IV.

THE SUN.

THE recent progress in Astronomy has been principally in the direction of the Sun. This is owing to the improvements in the spectroscope and the great advances in celestial photography. What, then, does Astronomy teach us regarding the peerless orb of day?

The diameter of the Sun is 860,000 miles. If the Sun could be divided into a million parts, each one of them would greatly exceed the earth in bulk; and the Sun weighs more than 326,000 earths. The mass of the Sun is more than 745 times the united masses of all the other bodies within the solar system.

As matter attracts in proportion to its mass, it is his great weight that enables the Sun to hold in their places the planetary bodies that he governs, and prevent them from rushing away wildly into space. All our planetary bodies are moving very rapidly, and, according to the first law of motion, would, unless prevented by the Sun, sweep on for ever in straight lines through the mighty realms of space.

The Sun is intensely hot. Its temperature far exceeds any artificial heat with which we are acquainted. It is much above that of the electric arc. When we get to the top of a lofty mountain we are nearer to the sun than when we are on the surface below. Still it is colder on the mountain's top than below. This is seemingly a paradox, as the nearer we are to a heated body the more of its warmth we should feel. The reason of the mountain's cold is this: The air lets the heat of the Sun pass through it without retaining any. Air is diathermanous, and is heated by convection. The layer of air in immediate contact with the earth's surface is heated first, and being thereby rendered lighter, it ascends. The colder layer above descends to replace the first layer, and being in turn heated, it too ascends; and so on.

On a summer day it is warmer inside a green-house than outside, because the glass, while permitting the heat to pass in, will not let it pass out so readily. The earth resembles a green-house, where the air replaces the glass panes. If we had no atmosphere, the earth's surface, like the mountain tops, would be covered with eternal frosts and snows.

The Sun appears to the unaided eye as a flat luminous circle of dazzling brightness, and absolutely without a blemish. When viewed through a telescope with a protected eye-piece the Sun has the appearance of a glowing globe with a mottled or granular surface.

The Sun consists of a nucleus, or interior globe, and three envelopes. The first envelope is the Photosphere; the second the Chromosphere, or Sun's true atmosphere; and the third the Corona.

The Photosphere.—The bright granular surface seen through the telescope is the photosphere, or, as its name implies, the sphere of light. To most observers this visible disc appears as if spread over with rice-grains, but an English astronomer, Nasmyth, claimed that it resembles a surface strewn with bright willow-leaves.

When the Sun is viewed with a telescope of even moderate size its bright granular surface is seen to be pitted with black spots. These spots are occasionally very numerous. They vary in number and size from time to time. They are observed to have a regular constant motion across the Sun's face.

From the common motion of all the spots in the same direction, it is concluded that the Sun turns on its axis in an interval of about 25 or 26 days. An extraordinary

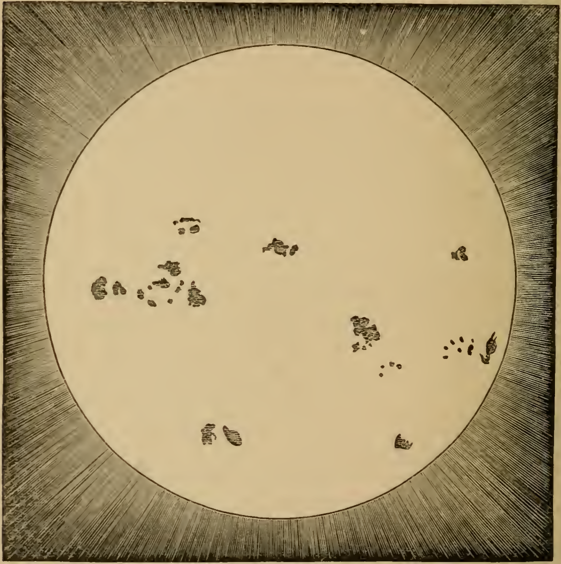

Fig. 4.—Sun Spots.

feature of the Sun's rotation is that it does not turn like the earth all-of-a-piece, but some parts move faster, and, indeed, make more turns, than others. This is a strong argument against the Sun's solidity. The equatorial regions revolve in a shorter time than do the higher latitudes.

Carrington computed the equatorial period at a little less than twenty-five days, and that of latitudes 50° at twenty-seven and a half.

The spots usually present a dark central part, strongly contrasted with the brighter margin. The dark centre is called the umbra or nucleus. The umbra is surrounded by a border, not so dark as the centre nor so bright as the disc. This border region is called the penumbra. It appears ordinarily of a uniform grayish tint. This penumbra, when highly magnified, appears streaked with radiations pointing towards the spots' centre. The spots are mostly found in groups. A large spot frequently breaks up into a number of smaller ones. A spot may live only a few days, and may survive several months.

Faculæ.—The surface of the Sun is not uniformly bright. It is brightest at the centre and the lustre gradually fades as we approach the edge. We frequently see scattered over the Sun's disc luminous patches or tongues, called faculæ, much brighter than the surrounding regions. Although appearing as bright fissures in the Sun, the faculæ are in reality above the solar surface. They are most apparent towards the Sun's rim, because of the comparative darkness of these outer regions. The darkening of the Sun's face toward the edge is caused by its atmosphere. The rays of light emitted from the vicinity of the edge have to travel through a greater depth of atmosphere than those from the central regions. Our own atmosphere acts similarly on the light rays reaching us. As we gaze upon the Sun when overhead, we see it through a less amount of air than when we view it upon the horizon. And so it is brighter in the zenith than when rising or setting. If the Sun had no atmosphere it would be about twice as bright and hot as it is, and its color much bluer.

According to Professor Langley, the photosphere is purely vaporous, and its mottled aspect is due to the appearance of numerous faint dots on a white background of fleecy clouds resembling our cirri. By using high magnifying powers these clouds may be divided up into numbers of small, intensely bright bodies floating apparently in a dark medium. The dark openings between these small bright floating bodies are called pores. These pores are of different sizes. The small bright bodies may be again broken up into still smaller bright particles. The photosphere would thus appear to have three orders of brightness: the cloud-like appearances; the rice-grains into which these clouds can be resolved; and a still finer division of small bright granules composing the rice-grains. Langley considers that the mottled appearance of the photospheric clouds is caused by a vertical circulation of currents, absorbing into the Sun's interior the cold matter from without, and sending forth heated matter from within towards the surface.

Spots.—In 1610 Galileo and Fabricius first discovered the existence of sun-spots. Galileo considered them solar clouds, and was the father of the cloud theory. Simon Marius was the author of the slag theory, and regarded them as the cindery refuse of the solar combustion. Derham (1703) was of the opinion that they are solar volcanoes. Lalande looked upon them as rocky elevations. Wilson (1774) regarded them as vast excavations in the Sun's substance. Sir John Herschel (1837) noticed that the spots occupy two zones on each side of the Sun's equator. These zones, or belts, extend from the 6th to the 35th degree of latitude on both sides of the solar equator.

Carrington was the first investigator of the drift of spots across the Sun's face. Sir John Herschel suggested the cyclonic theory of sun-spots in 1847, and Faye, in 1872, the whirlpool theory. Both these theories are now generally abandoned.

Heinrich Schwabe, of Dessau, was the first to announce the periodicity of sun-spots. This he did in 1843, and fixed the period of their alternate abundance and scarcity at ten years. Dr. John Lamont, in 1851, estimated the period at 10⅓ years. Rudolph Wolf, in 1852, placed the period at 11.11 years. In 1859 Wolf, after further thought on the subject, concluded that although the mean period is 11.11, still there is considerable fluctuation on either side of this mean. The interval between two maxima may reach 16½ years or descend to 7½ years. It is also understood that the spots increase more rapidly than they decrease, and that neither the increase nor decrease is uniform.

Two other sun-spot periods have also been discovered, one of 55½ years, and one of 222 years.

There is a close connection between sun-spot periods and magnetic changes upon the earth. Humboldt noticed that magnetic "storms" attained their greatest violence every ten years, and Sabine announced the correspondence between the sun-spot periods and the ebb and flow of magnetic change.

There is a feeble connection between sun-spot periods and the lustre of certain variable stars. An endeavor was early made to connect spot periods with the weather. William Herschel made the first attempt of this kind. He thought that a great emission of light and heat accompanied an increased number of spots.

Schwabe studied the matter carefully, but failed to discover any connection between the spots and weather changes. Wolf, in 1859, announced that he could detect no connection between these phenomena. This question of the influence of spots on the weather has still, however, received no satisfactory answer. There would seem to be some grounds for the opinion that increased rainfall attends the maxima of spots.

The Aurora Borealis is intimately associated with solar disturbance. The aurora borealis, sun-spots, and magnetic activity rise and fall so closely together that they must depend upon a common cause.

The spectrum of sun-spots, with some minor difference, is the same as that of the Sun. The same vapors are found in the sun-spot cavity as in the unbroken solar surface. The vapors in and about the spots often move, by the testimony of the spectroscope, with a velocity as high as 320 miles a second. The temperature of the spots is lower than that of the photosphere.

There is a suspicion that the planetary movements have a slight influence on sun-spots. There is, however, nothing definite in this respect.

Many of these spots cover areas on the Sun of vast proportions. Some of the great ones have measured over a billion square miles, or more than five times the terrestrial surface. The cavities of the spots are very deep. We can gaze down into some of them to a depth probably of five thousand miles. As we look down into the vast depths, we see only volumes of circling vapors, with no evidence of either solid or liquid groundwork.

The photosphere is a surface of condensation, being the limit set by the cold of space to the Sun's internal process of heat convection. Every cooling cosmic body has a surface so defined. The stores of heat of the Sun's interior reach the surface by means of vertical convection-currents. The photospheric clouds may probably be composed of carbon, silicon, and boron. The "grains," or bright parts of the photosphere, represent the upper terminations of the ascending warm currents, and the descending cooler currents produce the darker parts, or pores. The grains are computed by Langley to compose one-fifth of the photospheric surface, and to furnish three-quarters of the Sun's light. Janssen

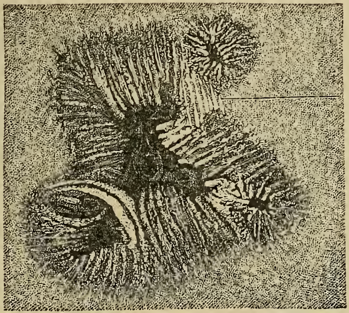

Fig. 5.—Sun-Spot (Secchi).

calculates that if the whole surface of the Sun were uniformly as bright as these grains, it would emit from ten to twenty times its present amount of light. The photosphere is the seat of the Sun's light and heat.

Owing to the awful brightness of the photosphere, the two outer solar envelopes, the chromosphere and corona, cannot ordinarily be seen through the telescope. These solar surroundings are visible only during a total eclipse of the Sun, or through a spectroscope.

Solar Eclipses.—A solar eclipse is caused by the passage of the moon's dark body between the earth and Sun. The moon, in its translatory motion around the earth, frequently passes between us and the Sun. The solar eclipse always takes place at new moon. The moon is then in conjunction, or almost in a line between the earth and Sun. If the path of the moon were exactly on the ecliptic or apparent path of the Sun. there would be a solar eclipse at every new moon. But the path of the moon is inclined to the Sun's path, or the ecliptic, by an angle of five degrees and eight minutes.

The plane of the moon's path being thus inclined to the plane of the ecliptic by this angle, it necessarily crosses the plane of the ecliptic at two points. Half of this plane is above, and the other half below, the plane of the ecliptic. The moon makes a revolution of its orbit in 29½ days which is the length of a lunation. The moon is half a lunation above the plane of the ecliptic, and the other half below it. The two points where the plane of the moon's path intersects the ecliptic are called the moon's nodes.

Where the moon crosses to go north or above the ecliptic is called the ascending node, and where it crosses to go south or below, the descending node.

If the moon's path were less inclined to the ecliptic there would be more eclipses in any given number of years than now take place. If the moon's path were more inclined to the ecliptic than it now is, there would be fewer eclipses.

The time of the year in which eclipses happen depends on the position of the moon's nodes on the ecliptic, and if that position were always the same, the eclipses would always happen in the same months of the year. Owing to the effect of the Sun's attraction upon the moon, the lunar nodes move backward at the rate of 19 degrees and 19 minutes per year; and it takes the Sun 20 days to travel that distance, so that the eclipses must take place 20 days earlier each year, or at intervals of about 346 days.

In a period of 223 lunations the nodes return to the same place. This period of 223 lunations requires 6,585 days, 7 hours, and 42 minutes, or about 18 years and 11 days. Therefore, after a lapse of 18 years and 11 days from any eclipse, we shall return to a similar eclipse; and it will be an eclipse of about the same magnitude as the one from which we reckon. This period was discovered by the Chaldean astronomers three thousand years ago, and they were thus enabled to calculate to within less than one day of the true time of an eclipse. Modern astronomers, by a more elaborate method, can compute to the precise second the approach of an eclipse.

The moon is a much smaller body than the Sun, but owing to the Sun's greater distance from us, the apparent size of the moon is generally equal to the Sun's apparent size. The path of the earth in its translatory motion around the Sun is an ellipse. The Sun is located at one of the foci of this ellipse. At the winter solstice the Sun is much nearer to us than at the summer solstice. This variety of distance increases or diminishes the Sun's apparent magnitude, so that sometimes it is greater, sometimes less, and sometimes equal to the moon's apparent magnitude.

The moon's orbit is also elliptical, and our satellite is sometimes nearer to us than at other times, and so its apparent magnitude varies a little from time to time.

When the apparent size of the moon is greater than the apparent size of the Sun, the moon cuts off the sunlight completely from a portion of the earth, and renders that portion almost as dark as night. But why a portion, and not the whole illuminated half of the earth? The moon is a much smaller body than the earth, the moon's diameter being only a quarter of the earth's, so that at its best the shadow of the moon could cover only the one-thirteenth part of the earth's face. Besides, the shadow of the moon is shaped like a cone. The volume of the Sun is nearly thirteen hundred thousand times the volume of the earth, and the volume

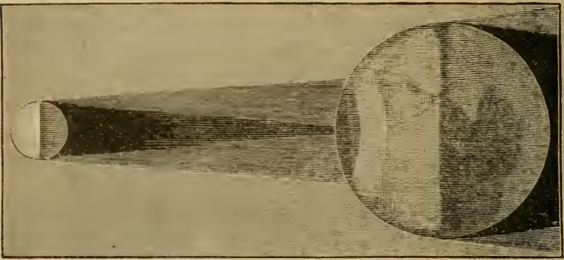

Fig. 6.—Total Solar Eclipse.

of the moon is only the one-forty-ninth of the earth's volume. Lines drawn touching the surfaces of the two spheroids of the Sun and moon, and produced until they meet behind the moon, will form the cone of shade cast by the moon in the earth's direction.

Sometimes, owing to the relative distances of the Sun and moon from the earth, the apex of this cone of shade just reaches the earth, and sometimes it does not. When the apex of the shadow reaches the earth and laps a little over, as it rarely does when favored by the small changes in the distances of the Sun and moon, at that place on the earth's surface touched by the shade there will be a total eclipse. When the shadow does not reach the earth there is only an annular eclipse.

There are three kinds of solar eclipses: partial, annular, and total. In a partial eclipse the moon does not pass directly between the earth and Sun, but slips by a little on one side, cutting off from view only a portion of the solar disc. In an annular eclipse, although the moon passes directly between us and the Sun, the apex of the lunar shadow does not reach as far as the earth, and there consequently appears around the moon's dark body a ring or annulus of light. In a total eclipse the Sun entirely disappears behind the moon's dark body.

The space embraced by a total eclipse is very small. The shadow appears as a dark circle whose diameter is usually about fifty miles. The diameter of this circle of shade scarcely ever exceeds 150 miles. But this black circle runs along after the moon, and in that way darkens a long, narrow strip of the earth's surface.

The duration of an eclipse is variable. We must distinguish, however, between its duration as regards the whole earth and one given place. The greatest possible duration of an eclipse at the equator is 4 hours, 29 minutes, and 44 seconds. The greatest possible duration of total obscurity at one given place on the equator is 7 minutes and 58 seconds.

Total solar eclipses are rare for the earth in general, and exceedingly so for any particular place, owing to the narrowness of the limits embraced.

The *Nautical Almanac* publishes, years in advance, all the indications of an eclipse. The exact time and the dimensions or phases of the eclipse are given for every spot of the earth. The size of the phases of an eclipse is expressed in almanacs in digits; a digit being the twelfth part of the diameter of the disc of the sun.

During the period of totality the sensation of awe is supreme. It grows so dark that the stars of the second magnitude appear in the sky, as do also the planets of the first order of brightness. There is a very perceptible lowering of the temperature. Animals and plants are unmistakably affected. Convolvuli, poppies, and night-shades have been seen to half open from being previously entirely closed.

Professor Langley describes the eclipse of 1869, which he viewed from a position near the Mammoth Cave in Kentucky, as follows: "First the black body of the moon advanced slowly on the sun, as we have all seen it do in partial eclipses, without anything noticeable appearing; nor till the sun was very nearly covered did the light of day about us seem much diminished. But when the sun's face was reduced to a very narrow crescent the change was sudden and startling, for the light which fell on us not only dwindled rapidly, but became of a kind unknown before, so that a pallid appearance overspread the face of the earth with an ugly livid hue; and as this strange wanness increased, a cold seemed to come with it. The impression was of something unnatural; but there was only a moment to note it, for the sun went out as suddenly as a blown-out gas-jet, and I became as suddenly aware that all around where it had been there had been growing into vision a kind of ghostly radiance, composed of separate pearly beams, looking distinct each from each, as though the black circle where the sun once was bristled with pale streamers, stretching far away from it in a sort of crown."

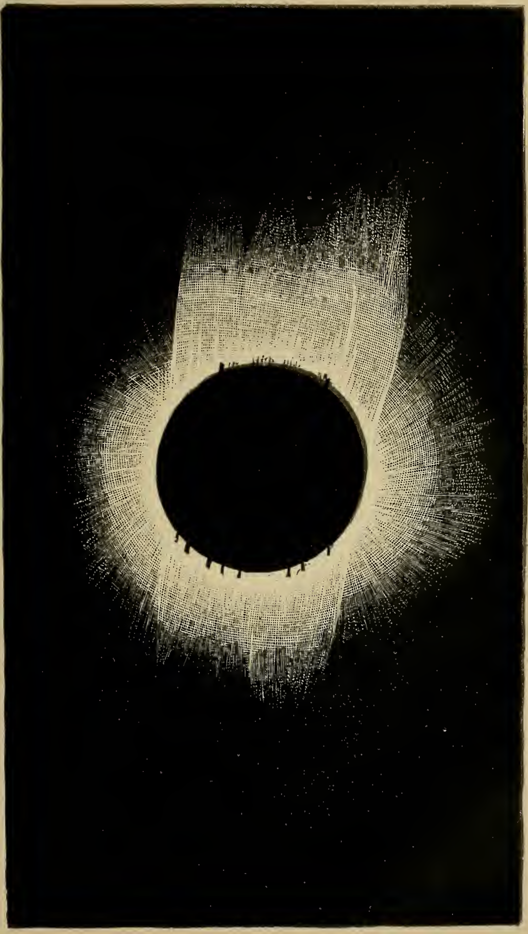

FIG. 7.—Another photograph of total solar eclipse taken by the party of Professors Pritchett and Charroppin, S.J., at Norman, Cal., January 1, 1889, showing the Corona.

Chromosphere.—During totality great tongues of flame, of a vivid crimson and scarlet color, are seen spreading out in various directions from the moon's limbs. These protuberances or prominences have been examined by the spectroscope, and found to be principally composed of hydrogen gas in a highly heated condition. These tongues of flame are eruptions of the sun's atmosphere. This atmosphere, called by Lockyer the chromosphere, is a thin envelope, composed principally of hydrogen, surrounding the whole surface of the sun.

Young, speaking of this chromosphere, says that "the appearance is as if countless jets of heated gas were issuing through vents and spiracles over the whole surface, thus clothing it with flame, which heaves and tosses like the blaze of a conflagration."

These tongues or prominences reach out to vast distances, some as far as 50,000 miles beyond the Sun's surface.

The spectroscope is now so perfect, however, that in its analysis of these flames it can dispense with an eclipse.

The Corona.—During totality, and just immediately before and after, a luminous halo surrounds the disc of the Sun. It is the corona, and it reaches out to an enormous distance, all the way from 300,000 to 1,000,000 miles from the Sun's surface. Occasionally it has been seen to stretch away into space as far as ten and even fourteen million miles. It is of almost indefinite tenuity, and has no counterpart in the material composition of our planet. Its color varies all the way from pearly white to red. The most striking feature of its spectrum is a single bright green line, which corresponds to no known element upon the earth.

Professor Hastings thinks that the corona is produced by diffraction upon the moon's edge. The phenomenon of diffraction may be seen in the early morning, when the rising Sun fringes with a line of light objects on the horizon.

The corona is not a solar atmosphere. It is, however, a solar appendage, and may be the resultant of the action of electrical repulsion, in one direction, and of gravity, in the other, upon some very attenuated substance. It does not gravitate upon the Sun's surface nor share in his rotation.

The spectroscope would seem to make it a compound, partly of a self-luminous gas, principally hydrogen, and the unknown substance of the green line; and partly of solid or liquid particles reflecting sunlight.

Solar Constitution.—The spectroscope has detected the presence in the Sun of the following elements:

Hydrogen,	Aluminium,	Nickel,	Strontium,
Sodium,	Iron,	Zinc,	Cerium,
Barium,	Manganese,	Copper,	Uranium,
Calcium,	Chromium,	Titanium,	Lead,
Magnesium,	Cobalt,	Cadmium,	Potassium.

Sun's Distance.—To find the correct distance to the Sun is regarded as the most important problem in Astronomy. In all celestial measurements beyond the moon the Sun's distance is the unit, and an insignificant error in this unit would become an enormous one when the nearest fixed star is reached.

It is also of moment to know this distance correctly when we undertake to calculate the Sun's temperature. For the comparative intensity of the solar rays at the earth's surface and at the Sun's surface is governed by this distance.

To compute the Sun's distance we must find its horizontal parallax. This is the angle subtended by the earth's radius at the Sun's distance. It is the magnitude of the earth's semi-diameter as seen from the Sun. This parallax, or angle, cannot be found directly by the finest instruments; not so much on account of its smallness as because of atmospheric troubles. Air refraction near the horizon prevents the proper measurement of so small an angle.

Astronomers have solved the problem by indirect methods. The relative distances of the planets from the Sun are governed by an inflexible law—Kepler's Third Law; or that the square of the time of revolution of each planet is proportional to the cube of its mean distance from the Sun. If we can find the correct distance of a single planet from the earth, the problem is solved. Mars is sometimes (after intervals of fifteen years) within thirty-five million miles of us. The first scientific estimate of the Sun's distance was made through Mars. Richer and Cassini made it in 1672. They computed the parallax at 9.5″, which corresponds to eighty-seven millions of miles.

Flamsteed, by the same method, made the parallax 10″, or 81,700,000 miles. Picard made the distance 41,000,000, and Lahire 136,000,000, miles.

Venus sometimes approaches to within 26,000,000 miles of us. This occurs when she passes between the earth and Sun, or during a transit. These transits happen in pairs at intervals of 105½ and 121½ years. The pairs are separated from each other by eight years, less two and a half days. The rarity of the transits is due to the large angle which the plane of the orbit of Venus makes with the Sun's path.

As the result obtained through the transits of

1761 and 1769, Encke gave us the classic number of 95,000,000 miles. He placed the parallax at 8.5776″, or 95,250,000; in round numbers, 95,000,000 miles.

Hansen, in 1854, and Leverrier, in 1858, declared that this distance would not accord with the motions of the moon; that it was too great by nearly 4,000,000 miles. Newcomb, in 1865, by taking Mars instead of Venus, made the figures 92,500,000.

The velocity of light affords another means of finding the distance to the Sun. Delambre, in 1792, from observations on the eclipses of Jupiter's satellites, computed that the time required for light to travel to us from the Sun is 493.2 seconds. Glasenap, a Russian astronomer, in 1874, made it 500.84 seconds.

Fizeau, Wheatstone, and Léon Foucault measured the velocity of light by means of revolving mirrors. Foucault announced, in 1862, that, according to this method, the Sun must be considered much nearer than by Encke's computation.

Elaborate preparations were made for observing the transit of Venus of December 8, 1874. It was hoped that great precision would be reached. But this hope proved futile, as the distorting effects of refraction, caused by the atmosphere of Venus, marred, in a great measure, the accuracy of the observations. There was a great want of unanimity in the results reached by astronomers.

Sir George Airy made the parallax 8.754″, corresponding to 93,375,000 miles. Stone obtained a value of 8.88″, or 92,000,000. From photography Mr. Todd deduced a parallax of 8.883″, or about 92,000,000 miles.

Skilful preparations were made for observing the transit of December 6, 1882. But this transit, likewise, failed to furnish a satisfactory solution of the great problem, and the range of doubt remained as wide as before, the atmospheres of the Sun, the earth, and Venus still combining to defeat precise observation. The following is a list of the Sun's distances from us as computed by eight great authorities:

Newcomb,	92,500,000.	Young, .	92,885,000.
Dr. Gill, .	93,080,000.	Faye, . .	92,750,000.
Todd, . . .	92,800,000.	Harkness,	92,365,000.
Ball, . . .	92,700,000.	Stone, . .	92,000,000.

Sun's Heat.—The heat of the Sun is indeed enormous. It is computed all the way from eighteen thousand to beyond a million degrees Fahrenheit. According to the law of decrease of radiant heat, the heat of the Sun at its own surface is 300,000 times more intense than at the surface of the earth. If the Sun were to come as near to us as the moon, the solid earth itself would not only melt like wax, but be dissipated into vapor.

The heat received on the half of the earth turned towards the Sun is but the two-thousand-millionth part of the entire amount radiated into space.

Effects of this awful Heat.—Owing to this enormous heat, the surface of the Sun is in a constant state of turmoil. Hurricanes and fierce cyclonic storms are incessantly sweeping over it with velocities exceeding a hundred miles a second. The unceasing tumult and uproar on every part of the solar surface are great beyond expression.

This heat also occasions mighty eruptions and explosions, by which matter is expelled to distances often of 160,000 miles with an initial velocity of 500 miles a second.

These vast eruptions produce cavities in the solar surface, and, in Secchi's hypothesis, are the origin of sun-spots.

Source of Solar Heat.—The Sun is constantly radiating its heat into space, and it would certainly grow cold unless some source supplied the loss. Among the many hypotheses purporting to account for this heat-supply, the gravity one appears the most circumstantial. According to this hypothesis, the Sun's own force of gravity causes a contraction of his diameter. It is a law of mechanics that contracting gas generates heat. The Sun is gaseous, but of great viscosity. A yearly shortening of the solar diameter of about 220 feet would be amply sufficient to supply the heat lost through radiation. This yearly contraction would be inappreciable at the Sun's great distance.

Helmholz first announced this hypothesis in 1854. It is the single pivot on which Laplace's Nebular Hypothesis now rests. Helmholz's hypothesis is strenuously opposed by geologists and biologists, as not allowing them sufficient time for their own hypotheses.

The Sun is the source of our light and heat, and, indeed, of all our comforts. Its bright rays gladden the day, and its reflected beams impart to the night its softer glory. Its chemical rays are necessary for the growth of all animal and vegetable life on the earth. This great star is the primary source of our clouds, our rain, our breezes, our stores of coal, and of the gaslight in our cities. To us it is truly the almoner of the Almighty.

CHAPTER V.

THE MOON.

THE Moon, relatively to us, is the heavenly body, after the sun, of most importance. It is our nearest neighbor in the realms of ether. It is the ever-faithful companion of the earth, and accompanies it in its yearly journeys around the sun, and in its mighty pilgrimage through space.

On account of its proximity, the Moon has been studied more than any other of the heavenly host, and, consequently, we are very familiar with its prominent features; and its laws, motions, and history are known with accuracy. We will first consider the features which our satellite presents to the unaided eye.

A Lunation.—One of the first things noticed about the Moon was its eastward motion among the stars. If, on a clear night, we observe that the Moon is close to a bright star, and watch both Moon and star for a few hours, we will perceive that the Moon has moved perceptibly away towards the east from the star. If we observe them at the same hour on the following night we will find that the Moon has moved towards the east about 13 degrees of an arc, corresponding to 50 minutes of time, in the interval of 24 hours. It makes a circuit of the heavens in 29½ days. The Moon travels from one position in the heavens back to the same position, relatively to the sun and earth, in 29½ days. This is the length of a lunation, or lunar month.

Moon's Phases.—As the travelling Moon thus changes its positions it presents different aspects or phases. It is new, in the first or last quarter, and full.

When the Moon is full it is on the opposite side of the earth from the sun, and shows its full illuminated disc to the sun and earth together. Moving onward

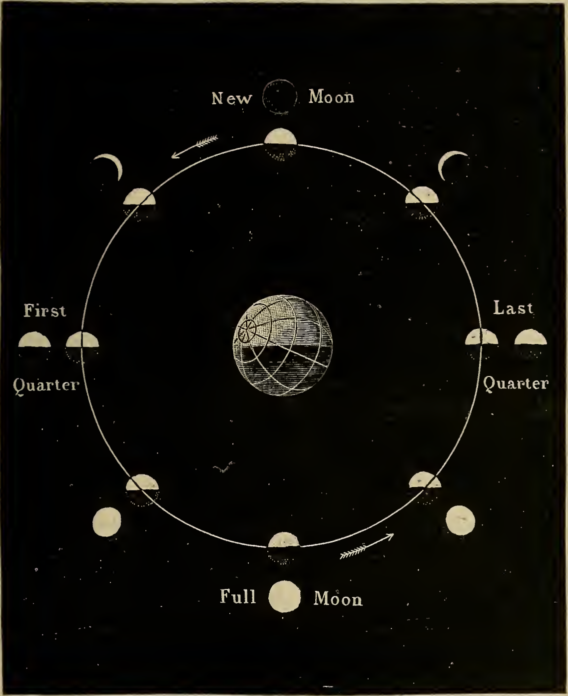

FIG. 8.—PHASES OF THE MOON.

in its course, it gradually passes more and more between the earth and sun, getting in its own shadow as far as concerns us, and the portion of its surface reflecting to us the sunlight grows smaller and smaller. Thus, after being full, it rises later each night, and each night the size of its enlightened disc grows less. About a week after the full but half its face is illuminated, the other half being dark; it is then in the third or last quarter. After this it presents a crescent form, until, in the space of another week, it disappears entirely; being on the same side of the earth that the sun is, it is swallowed up in the awful brightness of the sun's beams, and is completely invisible for about four days. After this it floats away from the sun and appears very low in the extreme west just after sunset. It then presents a bright crescent, very slender, and the convexity towards the sun, as is natural, since its light is borrowed from that luminary.

The crescent thence grows from night to night for the space of a week, when, having receded 90° from the sun, half the Moon's disc is illuminated; it is then in the first quarter. After this the disc becomes more and more illuminated, the phase increases in size until the Moon becomes full again; and so the phases succeed each other as before. Thus does the Moon constantly go through the same successive phases, presenting new Moon, first quarter, full Moon, and last quarter.

Earthshine.—When the Moon is very new its dark part is faintly illuminated and becomes visible to us. This feeble illumination of the dark part is known as earthshine, and is the light of the earth reflected back to us from the Moon's night side. The earth's disc is 13½ times that of the Moon, and, as a consequence, the earth shines on the Moon with 13½ times the intensity that our satellite shines on us.

The color of the moonlight is yellow, while the color of this earthshine is ash-gray. With a powerful telescope mountain peaks can be distinguished in this ash-gray region. The intensity of this ash-gray light varies according as continents, great forests, sandy deserts, or oceans throw their reflection upon the Moon.

The ash-gray may occasionally change to olive-green. Lambert, an observer, relates a change of this nature as follows: "The Moon, which then stood vertically over the Atlantic Ocean, received upon its night side the green terrestrial light which is reflected toward her when the sky is clear by the forest districts of South America."

Permanence of the Moon's Features.—Besides its motion around the earth, the Moon has a motion on its axis. It turns on its axis in precisely the same time that it revolves around the earth. This coincidence is not due to chance. There is a projection, or bulge, on the axis of the Moon pointing towards the earth, known as the major axis, and the earth, acting on this projection by gravitation, continually retarded the Moon's axial motion, until at length the motion round the earth and the motion on the axis corresponded in point of time. In consequence of this coincidence we never see but one side of the Moon. A person will easily understand how the Moon makes a complete revolution on its axis, and still keeps the same side always turned towards us, by placing a chair in the middle of the room and walking around it, keeping the face constantly towards the chair. Though your face is always towards the chair, nevertheless you turn completely around in going around the chair, so that your face turns to all the points of the compass. The period of these revolutions will, in future, always correspond, because the force that produced their isochronism will maintain it.

The aforesaid bulge was produced upon the Moon by the tidal action of the earth on the Moon's plastic mass. Tidal action may, then, be said to have caused this isochronism.

Sidereal Revolution.—In 29 days, 12 hours, 44 minutes, and 3 seconds the Moon returns to occupy the same position with respect to the sun and earth, and this is called a lunation; but the Moon makes a sidereal revolution of its orbit, or moves from a fixed star back to the same fixed star in 27 days, 7 hours, 43 minutes, and 11½ seconds. A difference of more than two days is caused by the earth's motion of translation in its orbit at the same time. While the Moon is going around her orbit, the earth travels quite a distance in her own path, and it takes the moon a little over two days, after finishing her course, to overtake the earth.

Moon's Distance and Diameter.—Professor Adams computes the mean distance between the centres of the earth and Moon to be 238,793 miles. The path of the Moon is elliptical, or oval, in shape, and so our satellite is sometimes nearer to the earth than at other times. The greatest difference in the distances may almost reach thirty-nine thousand miles. In consequence of this change of distance, the apparent size of the Moon varies. Hansen gives 31′ as the measure of the Moon's apparent diameter. The sun's apparent diameter is 32′. The usually received measure of the Moon's real diameter is 2,160 miles. The Moon weighs about the one-eightieth of the earth.

When the Moon is in the zenith, or overhead, it is nearer to us by the earth's radius than when it is just rising or setting. Yet, by an optical illusion, it looks larger on the horizon than when overhead. This illusion is due to the eye contrasting the rising Moon with objects on the earth in the line of vision. Looking at the moon through a tube the illusion disappears.

Geography of the Moon.—When viewed through the telescope the Moon's surface appears terribly broken up and mottled. Its pitted face resembles a muddy plain into which showers of stones had been thrown. The hilly parts of the Moon's broken surface reflect sunlight better than the flat levels, and so the mountainous ridges look bright and the plains dark.

The ancients supposed the dark regions to be composed of water, and named them seas. The name of "seas" is still retained, although it is understood that there is no water on the Moon.

One of the most striking features of the Moon's disc is an oval spot, of a mixed grayish and dark olive tint, close to the western limb. This is the Mare Crisium, or Sea of Crisis. It looks darker than any other of the so-called seas, on account of its isolated position, and, consequently, more striking contrast with the surrounding white. The Sea of Crisis contains 12,000 square miles.

The Sea of Tranquillity lies between Crisis and the Moon's centre. Tranquillity contains 23,200 square miles.

The two seas running up from Tranquillity are Plenty and Nectar. The western one is Plenty, while Nectar is nearer to the Moon's centre.

Reaching northwardly from Tranquillity is the Sea of Serenity, rendered very striking by the presence of a bright ray running through its entire length.

East of this last is the Sea of Rains, containing 64,000 square miles.

East of the Sea of Rains is the extensive but poorly-defined Ocean of Tempests, with an area of about 360,000 geographical miles.

Far to the southward of Tempests lie the Sea of Humors and the Sea of Clouds.

The spots on the Moon cover about two-fifths of the whole disc.

Mountain Chains.—The most remarkable of the lunar mountain chains are the Alps, the Caucasian chain, and the Apennines. These three great ranges surround, as by a semi-circle, the Sea of Rains. The Seas of Serenity and Vapors are separated from the Sea of Rains by the Apennines.

The Seas of Rains and Clouds are divided from the Ocean of Tempests by the Carpathian and Oural Mountains.

The Sea of Serenity has the Taurus Mountains on the west; and the range of the Pyrenees lies between the Seas of Plenty and Nectar.

The Mountains of Dörfel and Leibnitz are at the southern pole. Westwardly lie the Altai Mountains, and close to the western limb are the Cordilleras and D'Alembert ranges.

The Apennines are 373 and the Altai Mountains 276 miles long.

Mountain Scenery.—There are four varieties of mountain scenery on the Moon: Insulated mountains, rising from level plains and shaped like sugar-loaves; mountain ranges somewhat resembling the great chains on the earth; circular ranges encompassing, like a mighty rampart, a plain or great cavity; lastly, central mountains, or mountains in the centre of circular plains.

The height of the lunar mountains may be computed by measuring the distance of their illuminated summits from the enlightened part of the disc with a micrometer, and obtaining at the same time, by observation, the positions of the sun and Moon. The height of the lunar mountains is known as accurately as that of the chief mountains on the earth.

Mountains on the Moon.—Among the loftiest mountains on the Moon are a peak of the Leibnitz range, 41,900 feet above the valley; Dörfel, 26,691 feet; Curtius, 22,227 feet; Casatus, 21,234 feet; Calippus, 18,579

Fig 9.—Photograph of a Lunar Phase by Professor Charroppin, S.J., St. Louis University.

feet, and Huyghens, 18,060 feet in height; and the crater walls of Newton, 23,853 feet deep.

The best time to see the really broken character of the lunar surface is to observe it at the first or last quarter. Along the line of separation of the light and shadow, called the Terminator, the interior of the annular cavities seems quite black, whilst at intervals luminous points show themselves detached from the enlightened portions of the Moon. These brilliant spots are mountain tops, and according as they are observed at the first or last quarter, reflect the Moon's morning sun or the sunset rays which linger after the plains are enveloped in shadow.

Caverns.—Numbers of immense caverns lie all over the Moon's surface. Nearly one hundred of them can be distinguished, grouped together in the south-west part alone. The mouths of the caverns are mostly surrounded by mountain ridges, which reflect light very well, and give a bright appearance to those parts of the Moon where they abound.

Lunar Volcanoes.—The number of extinct volcanoes on the Moon bears testimony that it must have, during its period of activity, suffered frightful convulsions.

Craters.—The size of the lunar craters is enormous. The diameter of the crater Ptolemy is 114½ miles; Plato, 60 miles; Copernicus, 56 miles; Tycho, 54 miles, and of Aristarchus 23 miles.

Aristarchus lies between the Sea of Rains and the Ocean of Tempests, and is the most brilliant spot upon the surface of the Moon. So bright is it, indeed, that many observers, with Herschel, thought it a living volcano. It is now, however, conceded by its best students that the Moon has no living volcanoes, and that the degrees in brightness can be accounted for by the nature of the materials reflecting the sunlight.

From our acquaintance with the earth we can glean no idea of the torn nature of the Moon's surface, nor the extent of its territory eaten up by craters. Many attribute the ragged appearance of our satellite to the small force of gravity upon its surface. Gravity upon the Moon's surface is less than one-fifth of what it is upon the earth's surface. The Moon draws down bodies and holds its own matter together with less than one-fifth of the earth's attractive force. For this reason it is argued that the internal forces, being less controlled, acted the more readily in upheaving the Moon's surface.

Others say that the condition of the Moon's surface is due to the absence of water. The volcanic action of the earth has been much disguised by the effects of water, its sedimentary deposits covering up the work of fire. The Moon being void of water, the work of its internal fires is plainly visible.

The Moon without Water.—If water existed on the Moon's surface it would rise in vapor, and the telescope could detect a cloud 200 yards in diameter. No cloud has ever been seen floating above the Moon.

Again, a great body of water would reflect the sun's image in such a way as to be perceived by the telescope. Such a phenomenon has never been witnessed.

The polariscope, moreover, adds its voice to the demonstration of the non-existence of water on our satellite.

The principle of the polariscope is, that if a ray of light is reflected or transmitted at certain angles of incidence, it is rendered incapable of being again reflected or transmitted excepting at certain angles of incidence. Two mirrors are so arranged in a frame that they may be placed at any angle to each other; one of them is fitted to revolve, and has an index to note the degrees, and thereby determine its position in reference to the other mirror. This delicate test shows that the sunbeams reflected from the Moon have touched no liquid surface.

The Moon has no Atmosphere.—The proof of this is the sudden extinction of the light of a star when occulted by the Moon. Twilight before the rising and after the setting of the sun is caused by the earth's atmosphere reflecting and refracting the rays of light. Had the Moon an atmosphere, however rare, the light of the star would be visible some time after the beginning, and before the end, of the calculated time of an occultation. This test would detect a lunar atmosphere with a density less than the one two-thousandth part of that of the earth's.

Luminous Bands.—Great numbers of luminous bands appear, running along the Moon's surface from the tops of some of the high craters. More than a hundred of them run down the slopes of Tycho. Some observers consider them to be streams of volcanic matter erupted from the craters, supposing this lava to be a better reflector of light than the rest of the Moon's surface. Others think them fissures produced by the reaction of the Moon's interior on its exterior.

A similar appearance results from filling a globe of glass with cold water, and plunging it into warm water; the water confined in the glass expands, breaking the glass and producing radiating fissures.

Rills—The rills differ from the luminous bands in being formed of two parallel slopes, with a sunken way between them. They are bright in the full Moon, but in the other phases dark, one of the ridges throwing its shadow into the trench. Formerly they were thought to be ancient river-beds; but this is now given up, as they are known to cross high mountains and the sides of craters. The depth of the rills varies from 450 to 700 yards. Their width often reaches a mile and a half, and their length varies from 10 to 125 miles.

Moon's Axes.—The Moon's figure is an ellipsoid with three unequal axes. The shortest axis is the one on which it revolves, and is almost perpendicular to the ecliptic or earth's path. The mean is that which lies in the direction of the Moon's motion of translation. The longest is the one that points towards the earth. It is supposed that the shortening of the axis of revolution is due to the action of centrifugal force while the Moon was in the plastic state. The lengthening of the long axis is attributed to the earth's action of gravitation upon the Moon when in the liquid or plastic condition. The effect of this attraction would be to draw the matter on this side of the Moon towards the earth, and draw the Moon away from the matter on the other side. The result of these forces would be to lengthen the Moon in the earth's direction.

Librations.—The path of the Moon around the earth is elliptical or oval, and, as a consequence, it moves more rapidly in the parts of its path nearest to the earth than in the parts more remote. Its motion on its axis is uniform. Because the motion on the axis is uniform, and that in the orbit variable, the Moon reveals to us a little sometimes of one side and sometimes of the other that would otherwise be invisible. This is called the Moon's libration, or swaying in longitude.

The axis of the Moon not being quite perpendicular to the plane of its path, our satellite, in one part of its revolution, reveals more of the region around one of the poles, and in another part, more of the region around the other pole, and so gives its axis the appearance of a tilting motion. This is called the Moon's libration in latitude.

The moon has also a diurnal libration, caused by the earth's rotation. The Moon always turns the same face to the earth's centre. We see it from the surface. When the Moon is on the meridian we view it as we would from the earth's centre; but when the Moon is near the horizon our circle of vision takes in more of the upper limb than would be presented to a spectator at the centre of the earth. Hence we see a portion of one limb while the Moon is rising, which is gradually lost sight of, and we see a portion of the opposite limb as the Moon sinks to the west.

Owing to these librations, we see more than one-half of the Moon's surface. If the lunar surface be represented as 1,000, the part entirely invisible will be represented by 424, and the part visible by 576. The best students of the Moon say that there is no essential difference between the portion of the Moon always visible to us and the seventh part, generally hidden from our gaze. From this is concluded the similarity between the visible and invisible portions of the Moon.

Eclipse of the Moon—An eclipse of the Moon is caused by the interposition of the earth between the sun and Moon. If the Moon's path corresponded with the ecliptic we would have a lunar eclipse every full Moon. As these paths are inclined to one another by a small angle, similar eclipses occur only after intervals of 18 years and 11 days, or 223 lunations.

A total eclipse of the Moon may last two hours. If we add the partial eclipse on each side of totality, a lunar eclipse may continue four hours.

The disc of the earth as seen from the Moon is 13½ times as large as the Moon's disc appears to us. When the earth's disc passes directly before the sun its shadow is more than great enough to cover the whole Moon at once, and there is a total eclipse present to every part of the Moon's surface at the same time.

An eclipse of the sun seen from the Moon is never so entirely obscure as an eclipse of the sun seen from the earth. This is due to our atmosphere. The solar rays, in traversing the lower strata of our air, are diverted, and purple the Moon with the tints of sunset.

Moon's Heat.—Lord Rosse, by employing a large reflector to concentrate the rays of the Moon at a focus, and using the delicate thermometer of the thermo-electric pile, found that the heat of the Moon produced on the earth an increase of one-fiftieth of a degree Fahrenheit.

Lord Rosse estimated the change of temperature on the surface of the Moon, according as it was turned to or from the sun, at more than 500 degrees Fahrenheit. During the lunar night he computes the temperature at two or three hundred degrees below zero, and during the lunar day at as much above. The reason for this change is that the Moon, revolving on its axis during a lunation of 29½ days, has about fifteen of our days of day and fifteen days of night. During fifteen days the sun is incessantly pouring his heat upon the Moon, without modification from either atmosphere or moisture or clouds. During fifteen days of night the heat radiates into space, neither atmosphere nor cloud to interpose.

Recent experiments, however, would go to show that the temperature of the lunar surface is exceedingly low, even during its day-time, owing to the absence of atmosphere. It is well known that the higher we ascend from the earth's surface the thinner grows the air and the colder it becomes. If we could go high enough to find the air entirely gone, the cold would grow intense, and while the direct solar rays would actually burn our skin, the thermometer would show the cold around us to be arctic. According to Ericsson, this applies to the Moon equally as to the earth, and on our satellite's surface, owing to the absence of atmosphere, the mercury in the bulb of the thermometer would freeze never to melt again. Direct measures of lunar heat lately made confirm this opinion, and indicate that the Moon's surface, even in sunshine, must be always cold. Ice once formed there would probably never melt.

Is the Moon Peopled?—The Moon being void of air and water, and having so extraordinary a geology and climate, it is impossible to conceive it peopled by organic beings.

The Moon as a Time-Piece.—The Moon is of great importance as a time-indicator. As the sun measures the year, so does the Moon the month. If we regard the sun as the hour-hand, the Moon is the minute-hand of the celestial dial.

The Moon and the Mariner.—Latitude and longitude are the elements required by the seaman to compute his course. He can find his latitude from the sun or a star, but only the Moon can give him his longitude.

The Moon and the Weather.—The Moon's influence on the weather, the clouds, and the atmosphere is imperceptible.

Harvest Moon.—About the time of the autumnal equinox the Moon, when near the full, rises about sunset a number of nights in succession. This occasions a number of bright moonlit evenings at the harvest-time, lengthening, in a manner, the day, and enabling the farmer to gather his harvest. The Moon's path at different seasons is differently inclined to the horizon. The inclination is least when the equinoxes are in the horizon, and the 13° which the moon travels eastward in her daily path will then carry her but a little way below the horizon, and she will rise near the same hour for several evenings together.

The Moon's services to the earth are manifold. She illumines the night; measures time; determines Easter Day, and consequently all the movable feasts of the

Fig. 10.—Photograph of a Lunar Phase, by Prof. C. M. Charroppin, S.J., St. Louis University.

calendar; governs the tides, keeping the great bodies of water pure and enabling seamen to launch their vessels; and, as a celestial index, points out to the mariner his path on the ocean.

CHAPTER VI.

THE TELESCOPE.

Before approaching the planets it may be well to premise a short description of that marvellous instrument, the Telescope, which is a most important aid to their proper study.

Galileo is credited with the invention of the Telescope.

There are two kinds of Telescopes, refractors and reflectors.

The Refractor.—A lens or prism has the property of refracting or bending a ray of light from its course, it being a principle of optics that light passing from a rare to a more dense medium is bent towards a perpendicular to the refracting surface. The refractor, or refracting Telescope, has for an object-glass a lens bounded by two convex surfaces, concave towards each other. This lens bends the parallel rays as they enter from their parallelism, and converges them to a focal point behind it. In this way the image of an object is formed at the focus behind the lens. Besides the large lens used as the object-glass, or objective, there is in the refracting Telescope an eye-piece or eye-lens, being a small lens to magnify and view the image formed at the focus of the large lens. These two, the objective and the eye-piece, are the essentials of a refractor.

The Reflector.—Reflectors, or reflecting Telescopes, form the image in the focus by reflecting the rays of light coming from the object by means of a concave parabolic mirror, made of polished metal or silver on glass. This mirror is called the speculum, and converges the parallel rays entering it to a focus in front, where the image is formed. This image must be viewed with an eye-piece similar to that of the refractor.

Magnifying Powers.—The magnifying power of the Telescope is the quotient found by dividing the focal length of the objective by the focal length of the eye-piece.

The rule of the French opticians for finding the highest magnifying power, usefully applicable to a Telescope, is to double the number of millimetres contained in the width of the aperture. A millimetre is the thousandth part of a metre, or the .03937 of an inch. An inch is equal to 25.4 millimetres.

Chromatic Aberration.—The first Telescopes were refractors. A fatal property of the glass lens rendered useless the making of an object-glass larger than three inches in diameter, and it required a century and a half to obviate the difficulty. Chromatic aberration was the obstacle. When light passes through a prism or lens two distinct operations take place, refraction and dispersion. Refraction is the bending of the rays from their course when passing from a rare to a more dense medium, and it is this property of a lens that gives it its utility as a telescope.

The power a lens has of separating the colored rays in a beam of light is called dispersion. Violet is dispersed to the greatest distance from the primitive course, and red to the least, and the other colors intermediately. This is chromatic (color) aberration (wandering-away), or the separation of the component colors of light.

Achromatism.—Euler, the great German mathematician, was the first to remedy chromatic aberration in theory, and Dolland, an English optician, in practice. This was accomplished by combining into one objective two lenses having the same dispersive, and unequal refracting, power. Crown and flint glasses were the materials used. The dispersion of flint-glass is double that of crown-glass, while their refraction is almost equal. By combining a convex lens of crown with a concave lens of flint of about half the crown's curvature we will have refraction without dispersion. The crown-glass is on the exterior. A lens so composed is said to be achromatic, or colorless. In the best object-glasses now used the crown is a double convex lens, and the flint nearly a plano-concave. In this way the two lenses fit exactly together, the concave of the flint fitting the convex of the crown, while the inner face of the flint is nearly flat. No two specimens of glass being precisely similar with respect to their relative dispersion and refraction, the optician must experimentally find their ratio in every objective he makes. The lenses are usually joined with transparent balsam or castor-oil.

Secondary Aberration.—In very large achromatic objectives a secondary aberration arises from the fact that flint-glass, as compared with crown-glass, disperses the violet end of the spectrum more than the red, and, consequently, throws a violet or blue areola around the object. No art can correct this defect, as it flows from the properties of the glass itself. It may, then, be said that we have attained the limit of power in the refractor. A refractor of thirty-six inches in diameter in all likelihood touches the acme of perfection.

The Eye-Piece.—The eye-piece of a Telescope is, like the objective, formed of two glasses. An additional lens, called the field-lens, is added to the eye-piece in most Telescopes for the purpose of gathering up the outer rays from the objective, and so aiding the eye-lens in giving distinctness to the image. The eye-piece is said to be positive when the field-lens is located between the eye and the image, and negative when the field-lens is so placed that the light beams are passed through it before reaching a focus.

The short focal distance of the opera-glass is due to its having the negative eye-piece.

Manner of Using.—The two principal ways of using the Telescope are, as an equatorial and a transit instrument.

The transit instrument is fixed immovably in the plane of the meridian, and directed towards the south. It catches but a momentary glimpse of the celestial object as it is rapidly carried into the field of view by the earth's diurnal revolution, and its use is to determine the motion of the celestial bodies. It is the mathematical instrument of astronomers.

The equatorial is so arranged that it follows the daily revolution of the celestial sphere, and is thus enabled to keep the same object constantly in the field of view for the purpose of thorough investigation. Usually, in the case of large equatorials, there is a clock-work attachment to furnish the necessary motion. The equatorial is the weapon of the descriptive astronomer.

Among the greatest refractors in existence is the 26-inch Washington equatorial, completed in 1873, and remarkable for its discovery of the two satellites of Mars, the most diminutive planetary bodies known to Astronomy. It held the primacy among refracting Telescopes for nearly eight years, when it was succeeded, in 1880, by the 27-inch refractor, made by Howard Grubb, of Dublin, for the Vienna Observatory. This was, in turn, succeeded by the 30-inch refractor made by Alvan Clark for the Pulkowa Observatory. Lastly comes the great 36-inch equatorial made by Alvan Clark for the Lick Observatory. It was first directed to the heavens from the summit of Mount Hamilton on the evening of January 3, 1888. It is a great success, and has already accomplished some wonderful feats. Among other things, it has given clear views of the tiny satellites of Mars when, owing to the planet's great distance, they were six times as faint as when discovered by Professor Hall with the Washington refractor.

Reflecting Telescopes.—The reflecting Telescope did not come into use for more than a century after the refractor, although its principle was suggested by Mersenne in 1639. With the reflector the image is formed in front of the mirror or speculum, and hence a difficulty arises in endeavoring to remove the observer out of the direct path of the rays from the object.

There are three plans for avoiding this difficulty, devised respectively by Gregory, Newton, and Herschel.

Gregorian Telescope.—James Gregory, who is usually credited with making the first reflector, placed a small concave mirror behind the focus, by which the light is reflected back again to a small opening in the centre of the speculum, where the image is formed, and may be viewed through an eye-piece fixed into this central opening.

The Cassegrainian Telescope.—The Cassegrainian Telescope is the same in principle with the Gregorian, and differs only in having the small mirror convex instead of concave, and so placed between the speculum and its focal point that the rays do not really come to a focus until they reach, by a second reflection, the eye-piece in the speculum's centre.

The Newtonian.—Newton placed a small plane mirror just inside the speculum's focus, making an angle with the axis of the Telescope of 45°, and so throwing the rays to the side of the tube, where they are focussed and form the image. An opening is made in the tube's side opposite the small mirror, into which an eye-piece is screwed.

The Herschelian.—Herschel's plan was to slightly tip the speculum so that the rays were focussed and the image formed at the upper margin of the tube, where an eye-piece was fastened. The observer, in viewing an object with the Herschelian telescope, must take his position at the upper end of the tube and look directly into it, turning his back to the object.

It is on the Herschelian principle, though with an additional mirror, that the mightiest reflector in existence is made. This is the telescope built by Lord Rosse at Parsonstown, in Ireland. Its speculum is six feet in diameter, and is made of an intractable alloy of two parts of copper to one of tin, admitting of a very bright polish. The Telescope is sixty feet long, and is the most powerful in the world.

In viewing a star the Telescope does not increase its size, for the star, owing to its awful distance, is but a point, and how often soever we may multiply a point it still remains a point, but it increases its brilliancy by gathering up more of its light rays. The diameter of the pupil of the eye is about one-fifth of an inch, and as surfaces are to each other as the square of their like dimensions, the amount of light received from a star through the Telescope will be as one-fifth squared to the square of the diameter of the aperture. An objective of six inches gives an increase of nine hundred times. Hence the brilliancy of a star as seen through Telescopes will be proportional to the square of the diameter of their apertures. When viewing a planet the Telescope increases its apparent size in the ratio of the focal distance of the objective to that of the eye-piece. But the amount of light is not increased, as in the case of a star. The reason is because the light has to be diffused over a larger surface—larger in proportion to the magnifying power.

There is a dispute concerning the relative merits of reflectors and refractors. As a summary of the discussion, it may be said that the refractor is the more durable and better working instrument, and the reflector the more powerful.

Limit of Power.—Is there a limit to the magnifying power of the Telescope? There is; and it is owing, not to the Telescope, but to the atmosphere.

The air is always in a state of waviness or trembling, occasioned by the cool air descending and the heated air ascending. The greater the magnifying power employed the more is this disturbance perceptible, so that when the power is beyond 1,000 a star, instead of appearing as a point, looks like a stream or glare of light. Climate may, in a measure, modify this difficulty; but it is safe to say that a magnifying power much beyond 1,000 diameters cannot be usefully applied.

The Micrometer.—The micrometer consists of a tube, across the opening of which are stretched two parallel threads. These threads are so arranged that they can be moved to or from each other by the turning of a screw.

The parallel threads are crossed by a third one perpendicularly.

This little contrivance is placed in the focus of a

Telescope, and the distance apart of two stars may be measured with great accuracy by adjusting the parallel threads respectively to the centres of the stars, and counting the number of turns and fraction of a turn required to bring the threads together. A graduated scale is devised for the turning-screw.

The micrometer is used in measuring the apparent diameters of the heavenly bodies, and other minute celestial distances.

The Heliometer.—This is an instrument devised for the accurate measurement of the apparent diameter of the sun or heavenly bodies. It is a Telescope the object-glass of which is cut vertically in half. One half is fixed in the tube, and the other half is movable, being mounted on a slide. Each half of the object-glass will form in the eye-piece of the Telescope a perfect image of the sun or heavenly body. A screw of delicate mechanism, with a graduated scale, moves the slide.

If the sun's diameter is to be measured, the halves of the lens are adjusted so that the images may touch one another, and then the distance between their centres will give the diameter of the sun in seconds.

The Meridian Circle.—The meridian circle is a large graduated circle attached to the axis of the transit instrument. The number of degrees through which the transit Telescope turns is easily read off from this circle. It is chiefly used to find the right ascensions and zenith distances of heavenly bodies.

CHAPTER VII.

THE PLANETS.

AMONG the host of stars visible to the unaided eye there are five that are seen to continually change their place and wander about among the others. These five were known to the ancients. They move about capriciously in the starry ranks, and for this reason were called by them Planets, or wanderers.

The Planets known to antiquity are Mercury, Venus, Mars, Jupiter, and Saturn.

The telescope has added to the number of the planetary bodies two other great ones, Uranus and Neptune, and two hundred and eighty-one lesser ones.

The Planets are the associates of the earth in space. and with it belong to the family of the sun.

All the Planets alike borrow their light from the sun.

When viewed with the telescope, the fixed stars remain as points of light, while the Planets present a visible disc.

The unaided eye distinguishes the Planets by their steady radiance. The twinkling of the fixed stars is probably due to the interference of light in its awful journey through space.

The distinguishing characteristic of a Planet, however, is its motion among the stars.

The planetary bodies are divided into two classes, the Major and Minor Planets. The eight large Planets, of which the earth is a member, are called the Major Planets, from their size and importance, and the lesser ones the Minor Planets.

The Major Planets are sub-divided into two groups, the inner and the outer group. The inner group embraces Mercury, Venus, the Earth, and Mars. The outer embraces Jupiter, Saturn, Uranus, and Neptune.

All the Planets revolve about the sun, are members of his family, and are governed and held in place by his great mass.

The orbits of the Planets are all similarly shaped, being ovals. All the Planets revolve in nearly the same plane, that of the Ecliptic.

There is still another division of the great Planets into inferior and superior. The inferior Planets have their orbits within the earth's, and are Mercury and Venus. The superior Planets have orbits beyond the earth's, and are Mars, Jupiter, Saturn, Uranus, and Neptune.

The six outermost Planets are attended by 20 satellites. The Earth has 1, Mars 2, Jupiter 4, Saturn 8, Uranus 4, and Neptune 1.

The direction of the orbital motions of the Planets is from west to east, or against the hands of a clock. This is, too, the direction of their rotations. It is also the direction of the motion of the satellites around their primaries, except in the case of those of Uranus and Neptune.

It is surmised that there is a law governing the periods of the axial rotation of the Planets, but it has not been established.

It is suspected that two undiscovered Planets exist beyond the orbit of Neptune. Two families of comets are known to travel in that distant region, and their movements would seem to indicate the presence there of two large planetary bodies. It is a mere suspicion.

MERCURY.

Mercury is the nearest Planet to the sun, and it was known to the ancients. Neither the name, nation, nor epoch, however, of its discoverer has been preserved. The first authentic record we have of an observation of the Planet is of one made in the year 265 B.C.

Mercury has phases like the moon, and they are explained on precisely the same principles as the lunar phases.

Mercury is an evening and a morning star. Mercury is very difficult of observation, being so near to the sun that it is usually swallowed up in his rays. It shines with a bright white light, and is, perhaps, equal in lustre to Sirius.

The apparent size of its disc, as seen through the telescope, varies from 5″ to 12″, according as it is viewed at its nearest or farthest approach to us. When beyond the sun Mercury appears round and small; and when nearly between the earth and sun it takes the form of a slender crescent. It is supposed to rotate on its axis in about 24 hours. The exact period of its rotation is not definitely known.

The Planet makes a revolution around the sun in nearly 88 days. Its average distance from the sun is 36,000,000 miles. It travels in its orbit with an average velocity of over 29 miles a second, or a hundred times more rapidly than a rifle bullet.

Its oval path departs from the circular form much more than that of any other of the Major Planets. Its greatest distance from the sun is 43,000,000, and least 30,000,000, miles. As a consequence, its velocity varies in the different parts of its orbit from 23 to 35 miles a second.

When Mercury is farthest from the sun the solar heat beats down on its surface with more than four times the intensity that it ever attains at the earth's surface; and when the Planet is closest to the sun this heat is nine times as great as the most intense that ever touches the earth.

The seasons on Mercury, owing to its short year, change much more rapidly than they do upon the earth. It is only 44 days on Mercury from mid-winter to mid-summer. In the space of six weeks the sun rises to Mercury to more than double his apparent size, and radiates upon the Planet more than double the quantity of light and heat.

A luminous margin has been seen by observers on different occasions during Mercury's transit across the sun's disc, and variously estimated at from one-third to two-thirds of the Planet's diameter in depth. From this it is thought that the Planet has a dense atmosphere. The measurements of the intensity of the Planet's light, however, render doubtful the very existence of an atmosphere. The climate of Mercury, even if it has a dense atmosphere, must be an extraordinary one.

Von Asten gives the weight of Mercury as the one twenty-fourth of the earth's.

The elongation of Mercury, or its departure, never exceeds 29° on each side of the sun. The Planet is sometimes above the horizon for two hours after the disappearance of the sun. The most propitious times to see Mercury with the unassisted eye are the spring for morning, and the autumn for evening observation, as the Planet is at those times north of the sun, and almost vertically over the place of sunset and sunrise.

Dark and bright markings, of a changeable nature, have been noticed on the Planet's disc, and many recent observers have regarded them as similar in character to those on Mars.

Mercury's nodal returns recur, under nearly the same conditions, after periods of thirteen years. The transits of this Planet across the sun's disc happen after average intervals of less than ten years. The longest interval between two successive transits is thirteen years.

The first recorded transit was observed by the illustrious Gassendi, on November 7, 1631. These transits always occur in May or November, because the Planet crosses the ecliptic in these months. The next transits will be on May 9, 1891, and November 10, 1894.

Mercury rotates on an axis inclined 70° to the plane of its path.

The spectroscope shows that the light of Mercury is reflected sunlight, and its spectrum is a faint echo of the solar spectrum. The spectroscope neither confirms nor denies the existence of a Mercurial atmosphere.

The theory of an intra-Mercurial Planet, hypothetically called Vulcan, is abandoned.

VENUS.

Venus has no rival in brilliancy among the starry host. The Chaldean shepherds praised its glowing beauty with such fervor that the East called it the shepherd's star. Hipparchus and Ptolemy called it Venus, probably on account of its matchless lustre and incomparable loveliness. Its brightness is, indeed, sometimes so intense that in a very clear sky it is visible by day.

Venus is the second Planet in the order of distance from the sun. It is an inferior Planet, since its orbit lies between the earth and sun.

The Planet shines by reflected sunlight, and it has phases like the moon. Owing to its distance, it shows no disc to the unaided eye, and its crescent form cannot be perceived without telescopic aid.

Its mean distance from the sun is about 67,000,000 miles.

Its orbit is nearer to a perfect circle than any other of the planetary paths.

Its day is 39 minutes shorter than ours. It revolves on its axis in about 23 hours and 21 minutes. There is, however, it must be confessed, considerable uncertainty in respect to this matter.

Venus traverses its orbit in 224.7 days. Its speed is next to that of the winged Mercury, being on an average 22 miles a second.

The Planet at times approaches as near to the earth as 24,000,000 miles, and again, at times, it recedes to a distance of 162,000,000 miles. Owing to this great difference in distance, the Planet presents very different aspects when viewed at different times through the telescope.

Venus never departs from the sun beyond 47°, and is thus visible but a short portion of the night.

The Planet oscillates from one side of the sun to the other, and becomes alternately morning and evening star. As morning star it was known to the ancients as Phosphorus; and as evening star, Lucifer.

The equator of Venus makes an angle of 53° 11′ 26″ with the plane of its path, so that its axis of rotation departs much more from a perpendicular to its orbital path than does the earth's.

The diameter of Venus is 7,660 miles, or 258 less than that of the earth. The mass of the Planet is computed at three-quarters of that of the earth. The density of the Planet is about .85 of the earth's, and it would weigh 4.81 times as much as an equal-sized globe of water.

The force of gravity on the Planet's surface is a little less than on that of the earth. Near the earth's surface a body abandoned to gravity would fall $16\frac{1}{12}$ feet in the first second; it would fall three feet less near the surface of Venus.

Astronomers take advantage of the transit of Venus to compute the distance to the sun. These transits are very rare. They occur in pairs, after intervals of $121\frac{1}{2}$ and $105\frac{1}{2}$ years. The pairs are separated from one another by eight years less $2\frac{1}{2}$ days. They occur in pairs separated by eight years because eight revolutions of the earth around the sun are performed in nearly the same period as thirteen revolutions of Venus. After eight years Venus and the earth are back in a line again, and near the same position relatively to the sun.

A short time before the beginning and after the end of a transit the globe of Venus is faintly perceptible. This is due to the Planet's atmosphere. It is thought that the atmosphere of Venus is somewhat more dense than the Earth's.

The spectrum of Venus does not materially differ from the solar spectrum. The spectroscope testifies, in a measure, to the similarity of the atmosphere of Venus and our own.

THE EARTH.

The Earth is the third Planet we reach as we travel outward from the sun. Its path is elliptical, or oval. Its mean distance from the sun is 92,500,000 miles. It is 3,000,000 miles nearer to the sun on January first than on July first.

There are many proofs of the Earth's rotundity. The first is from analogy. The sun, moon, and the planetary bodies are all round, and, accordingly, we conclude our own Planet to be similarly shaped. The Earth's shadow, cast on the moon during a lunar eclipse, is circular; the circumnavigation of the globe; the horizon is seen to expand as we ascend a mountain; and the polar star is perceived to sink or rise as we journey to or from the equator—these are other evidences of the Earth's sphericity.

The figure of the Earth is usually referred to as an oblate spheroid, or ellipsoid of revolution. This is really the figure that a molten fluid mass of matter of the size of the Earth, and whirling on an axis with the Earth's axial rapidity, would assume. The centrifugal force of such a revolving body would produce a projecting bulge at its equator and a contraction at its poles.

Geologists contend that the Earth's interior is now an ocean of liquid fire, and that the hard exterior crust is but the merest shell. As evidences of the awful heat of the Earth's deep interior they point to boiling springs, volcanoes, earthquakes, and particularly to the supposed gradual increase in the temperature of all deep mines of 1° F. for every 55 feet of descent after the first 100 feet.

The theory of regular increase is now, however, abandoned.

Admitting that there are really enormous quantities of heat in the Earth's interior, and such as, under ordinary circumstances, would reduce the metals to a liquid state, still the science of mathematics insists that the Earth is a rigid body, due, probably, to the intense downward pressure of its parts. The best mathematical analysis declares that the Earth must have the rigidity of steel that the phenomena of the tides may be satisfactorily explained. It is the difference in the behavior of the solid and liquid portions of the Earth under the influence of solar and lunar gravity that produces the tides. If the Earth were a vast ocean of liquid fire, with a thin crust or covering, there would be no tides, for the continents and seas would rise and fall together under the action of an external attraction. Moreover, dreadful tides would continually rise in this mighty igneous ocean, and flow around after the moon and sun. No crust could withstand the breaking of these tides.

Cavendish, by means of a torsion balance, endeavored to calculate the mass of the Earth. It is a law of gravitation that bodies attract in proportion to their mass. He compared the Earth's attraction with that of an equal bulk of lead.

Baille and Cornu, by an improvement on the process of Cavendish, computed that the Earth weighs 5.55 as much as a globe of water of the same size.

The height of the pole above the horizon is the latitude of an observer, or his distance from the equator. By means of the polar star a degree of the meridian can be measured. From careful measurements made on the Danube between Hammerfest and Ismailia, and in India, it is computed that the equatorial radius of the earth equals 6,377,377 metres, and the polar radius equals 6,355,270 metres, and the ellipticity $\frac{1}{288.48}$.

Pendulum measurements may be said to confirm these results.

The Earth has strictly no purely geometrical figure, and the nearest approach to its exact form would be an ellipsoid of three unequal axes.

MARS.

Mars is the first Planet whose orbit lies outside that of the Earth, or it is the first superior Planet. Of all the Planets, it bears the closest resemblance to the earth. Its surface is less obscured by clouds and vapors than that of any other of the Major Planets, and, on account of this and of its favorable position, we are better acquainted with the details of its surface than with those of any other heavenly body except the moon.

Its mean distance from the sun is about 141,000,000 miles. Its least distance is 128,000,000, and its greatest 154,000,000, miles. From this it is seen that its orbit departs considerably from the circular form. Indeed, the path of Mars has, next to that of Mercury, the greatest eccentricity of any of the orbits of the great Planets.

Mars is nearest to us when it is in opposition, or on the same side of the sun with the earth. It then may approach to within 35,000,000 miles of the earth.

Mars makes a circuit of its orbit in 687 days. Because the year of Mars is not a multiple of our year, its oppositions will occur at irregular intervals. Very favorable oppositions, however, recur at intervals of fifteen years. The Planet is much nearer to us at some oppositions than at others, owing to the difference in form of the orbits of Mars and the earth. The earth's orbit is nearly circular, and that of Mars very eccentric. The most favorable oppositions will be those occurring closest to the 26th of August.

Mars is more than four times as bright at the most favorable as it is at the most unfavorable oppositions. The last favorable opposition was in 1877, and the next two will occur in 1892 and 1909.

To the unaided eye Mars usually appears as a star of the first magnitude, of a ruddy color; indeed, it is the reddest star in the sky. The cause of its color is unknown.

The equator of this Planet is inclined to its path by an angle of 27°, so that the change of seasons on Mars is much more marked than on the earth.

The diameter of the planet is 4,200 miles. The volume of Mars is one-seventh of the earth's, double that of Mercury, and seven times that of the moon. The mass of Mars is a little more than an eighth part of the earth's. The force of gravity, or the weight of bodies, on Mars is one-half of that on the earth.

The atmosphere of Mars is much rarer than the earth's, and atmospheric pressure on the Planet's surface, instead of being fifteen terrestrial pounds to the square inch, as it is with us, is computed to be about two and a quarter pounds.

The surface of the Planet is thought to be about equally divided between land and water.

The polar snows are plainly visible upon Mars.

The markings on the Planet's surface are permanent features, and cannot be attributed to the presence of floating clouds. The telescope shows dark gray or greenish patches upon a deep yellow ground. On account of the permanence of these markings, the time of rotation of the Planet on its axis has been determined with the greatest accuracy. The period of rotation is 24 hours, 37 minutes, 22.7 seconds, and this is the length of the Martian day.

Schiaparelli, director of the Milan Observatory, claims to have discovered some curious features upon the Martian surface. What was formerly regarded as Martian continents he declares to be numbers of islands, separated from each other by a network of dark lines which he calls canals. These canals appear to be extensions of the Martian "seas," to connect them together, share their gray-green color, run in straight lines three or four thousand miles, and to be of a nearly uniform breadth of about sixty miles. The appearance of these peculiar formations on the Martian surface has been confirmed by other observers.

During the opposition of 1881–2 Schiaparelli announced that he saw not only these canals, but also other similar canals running along parallel to the first. He has drawn a marvellous map of the Martian surface, spread all over with pairs of parallel canals. The latest views of the Milan observer have not been implicitly received, and await confirmation.

Professor Asaph Hall, with the 26-inch refractor of the Washington Observatory, discovered, during the opposition of 1877 (August 11), two tiny satellites to the Planet Mars. The nearest to the Planet has been named Deimos, is about 5,800 miles from the Planet's centre, and revolves round the primary in 7 hours, 39 minutes, 14 seconds. The outer satellite is called Phobos, is distant 14,600 miles, and makes a circuit of the Planet in 30 hours, 17 minutes, 54 seconds. Deimos is about 18 miles in diameter, and Phobos 22½.

While Mars turns once on its axis, the inner satellite has sped around it three times. This is a striking anomaly in the planetary system, as it was always thought that the satellite could not revolve with greater speed than that with which the Planet rotates. The extraordinary feature of our system is supposed to be due to a retardation of the Planet's axial motion by the solar tides.

The path of Mars is inclined 1° 51′ to that of the earth, and the planet travels in its orbit at a speed beyond fifteen miles a second.

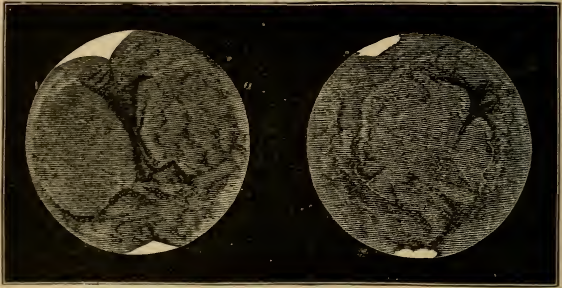

Fig. 11.—Views of Mars at two hours' interval. (Warren De La Rue.)

THE MINOR PLANETS.

The Minor Planets, or Planetoids, all revolve in the space between Mars and Jupiter. In the matter of size these small Planets are insignificant, ranging from 12 to 500 miles in diameter, and are entirely invisible to the unaided eye.

Vesta is the largest of the group, and Professor Pickering, from determinations of light-intensity, computes its diameter at 319 miles; while Professor Harrington, of Ann Arbor, assigns it a diameter of 520 miles. Pickering places the diameter of Pallas at 167, that of Juno at 94 miles; and Harrington holds that the size of Vesta and Flora together nearly equals that of all the rest.

Leverrier calculated that the mass of all the planetoids together could not possibly exceed one-fourth of the earth's mass; but it is very probable that this estimate is much too high, and that their united masses cannot exceed the $\frac{1}{400}$ of the mass of the earth, or $\frac{1}{20}$ of that of Mercury.

The number of the Planetoids now known is 281.

They travel around the sun, similarly to the great Planets, from west to east in elliptical orbits.

The mean eccentricity of their orbits is less than that of Mercury, and the average plane of their paths differs but slightly from that of the sun's equator.

The path of Pallas has the greatest inclination of any of the asteroidal orbits, and its angle is 34° 42′.

It is almost certain that these small Planets have no atmospheres.

Astronomers since Kepler's time have considered the void between Mars and Jupiter as extraordinarily great, and suspected the presence there of an undiscovered planetary tenant. An alleged law, discovered by Bode, strengthened this suspicion.

Bode took this series, 0, 3, 6, 12, 24, 48, 96, and adding 4 to each, formed the series, 4, 7, 10, 16, 28, 52, 100. Excepting the fifth number, 28, these figures almost represent the proportion of the distances of the Planets from the sun. The following are really the relative distances of the Planets from the central orb: Mercury, 3.9; Venus, 7.2; Earth, 10; Mars, 15.2; Jupiter, 52.9; Saturn, 95.4.

Although we now know that this discovery of Bode is but a coincidence and no law, still its announcement led observers to greater industry in their search for planetary bodies.

Piazzi, of Palermo, discovered the first asteroid on the first of January, 1801, and called it Ceres. In prosecuting his search, Piazzi resolved to examine all the stars in that part of the heavens bordering on the ecliptic. He examined a group of fifty stars at a time. He examined each group four times in succession before passing to a new group. The thirteenth star in the one hundred and fifty-ninth group was found to be a small Planet. It was discovered in the constellation Taurus, and appeared to be a star of the eighth magnitude. After a few observations, Ceres passed into a portion of its orbit where it was lost to sight in the rays of the sun.

Gauss, however, the great German mathematician, had discovered a method by means of which he could compute a Planet's orbit from three observations. When Ceres emerged again from the sun's rays Gauss had calculated that its path lay between the orbits of Mars and Jupiter, and was able to point out its place among the stars, so that it was immediately seen by observers.

In March, 1802, Olbers found a second planetoid, revolving also in the space between Mars and Jupiter, which he called Pallas.

Harding, of Lilienthal, caught a third small Planet in 1804, and called it Juno; and Olbers found another in 1807, and named it Vesta.

Thirty-eight years after the finding of Vesta, Hencke, of Driessen, discovered the fifth planetoid. After this discoveries followed rapidly, until we now have 281 of these lilliputian neighbors.

Palisa, of Vienna, discovered 60 planetoids; Peters, of

Clinton, U. S. A., 47; Luther, of Bilk, 23; and Watson, of Ann Arbor, U. S. A., 22.

The elements of the orbits of the planetoids, and other records concerning them, are published in the *Berlin Year-Book.*

Olbers, on discovering the great inclination of the orbit of Pallas, suggested his famous hypothesis, that the planetoids are the fragments of a disrupted great Planet that once filled the void between Mars and Jupiter. This hypothesis of Olbers is now abandoned.

Astronomers hope that in the near future the distance to the sun will be able to be computed with great accuracy through means of the minor Planets. The efforts in the past to find this distance correctly through the agency of Venus and Mars have failed of success, owing principally to the refraction of their atmospheres, and the rarity offered by them of an opportune position.

The small Planets have no atmospheres, and some of them approach so near the earth that their distances from us can be measured. About a dozen of them are little further away from us than three-quarters of our distance from the sun, and one or two will be suitably placed every year for this measurement.

Kepler's third law governs the relative distances of all the Planets from the sun. If, then, we can find the distance of one Planet from us, we can find our distance from the sun.

The planetoids are unequally distributed over the zone they occupy, but the greatest number are grouped at a mean distance from the sun 2.8 times that of the earth's.

Professor Daniel Kirkwood, of Indiana University, maintains that Jupiter strongly influences the planetoids, and has helped considerably to shape their orbits.

JUPITER.

Jupiter is the largest of the planetary bodies, and his orbit is the first beyond those of the swarm of planetoids.

Mass.—The mass of Jupiter is greater than the united masses of all the other Planets, great and small.

Distance.—Jupiter revolves at a mean distance from the sun of 482,000,000 miles, and the diameter of his orbit is 5.2 times that of the earth's.

Shape of Path.—The path of Jupiter around the sun is decidedly elliptical, the Planet's greatest distance from the central orb being 5.45, and least 4.95, times the earth's mean distance.

Speed.—The greater is a Planet's distance from the sun, the slower is its orbital motion; and Jupiter's velocity of only 8 miles a second to the earth's 18 is an exemplification of this. Jupiter makes a circuit of its great orbit in 4,332.6 days.

Time of Rotation.—Jupiter rotates on its axis in about 9 hours and 55½ minutes. His axial motion is much more rapid than the earth's.

Diameter.—Jupiter's mean diameter is about 85,000 miles, his equatorial being 87,500 and polar 82,500 miles. His equatorial bulge is much greater than the earth's, due probably to the greater centrifugal force of his much higher axial speed while in the plastic state. A point on Jupiter's equator rotates 27 times more rapidly than one on the earth's.

Not Solid.—It is concluded, for many reasons, that Jupiter is not a solid body. Jupiter's mass has been computed from the amount of gravitational influence he exercises on his satellites or moons. This computation has been confirmed by his action in shaping the paths of the minor Planets, and also in influencing the orbits of comets. Jupiter's mass is about 310 times that of the earth's, and his volume is computed as more than 1,200 times the earth's volume. From these figures it is easily seen that the specific gravity of Jupiter is not only less than that of the earth, but very little more than that of water. Indeed, the Planet's density is only 1.38 times that of water.

Primitive Heat.—It is more than probable that Jupiter is at present in a highly heated condition, having still retained a large amount of its original caloric. The changing features of the Planet's disc are indices of its internal agitation, caused by great stores of heat.

The Markings not Permanent.—The belts, or markings, on Jupiter are continually undergoing changes. Some of the changes are caused by the Planet's rotary motion, which in the space of five hours carries one whole hemisphere away from view, and replaces it by the opposite one. But, apart from the rotary changes, there are others, as new belts and fresh features are constantly appearing. Indeed, there are no permanent markings on the Planet.

Violent storms are known to sweep over the Planet's disc which cannot be occasioned by the sun's heat, since at Jupiter's surface its intensity is only the $\frac{1}{25}$ of what it is at the earth's surface. These storms are evidently caused by internal fires.

Not Self-Luminous.—This internal heat is not, however, sufficient to make the Planet self-luminous. Jupiter's brightness is reflected sunlight. The proof that Jupiter is not self-luminous is that the satellites throw shadows upon the primary when they pass between it and the sun, and the Planet renders the satellites invisible when it passes between them and the sun.

Jupiter reflects 62 per cent. of the light-rays impinging upon it. It is thought, from this great brilliancy, that the Planet must have some original luminosity.

Huggins and Vogel give the spectrum of Jupiter as showing the Fraunhofer lines belonging to reflected sunlight, and some lines due to atmospheric absorption. Some of these latter belong to aqueous vapor, some are unknown, and one agrees with a line in the spectra of some red stars. There is also observed in the spectrum of the Planet an absorption of blue rays, due to great depth of atmosphere. None of these lines would point to intrinsic light.

Dr. Draper, on a single occasion, thought that he obtained evidence, through photography, of a native emission of light from the Planet. It is concluded, however, that Jupiter sends forth no permanent light, though he may occasionally emit fitful gleams.

The flattening at Jupiter's poles is about $\frac{1}{17}$. The Planet's most remarkable features are the dark and light belts running in a common direction across its disc.

Red Spot.—For many years a large spot upon Jupiter, of a brick-red color and elliptical form, 25,000 miles long and 8,000 wide, awakened much interest in observers. It was situated just south of the great southern dark belt, and proved to be an atmospheric effect which has now almost entirely disappeared. The earliest record of this great spot's appearance is by Professor Pritchett, now of Glasgow, Mo.

All the visible features of the Planet are atmospheric, and we never see its real surface.

Jupiter's equator is but very slightly inclined to the ecliptic, and its orbit makes an angle of 1° 18′ 41″ with the earth's path in space.

Satellites.—Jupiter has four satellites, discovered in January, 1610. Io revolves around its primary in 1d., 18h., 28m., and 36s., is distant from it 267,000 miles, and is 2,400 miles in diameter. Europa revolves around the primary in 3d., 13h., 17m., and 54s., is distant 425,000 miles, and is 2,100 miles in diameter. Ganymede revolves in 7d., 3h., 39m., and 36s., is distant 678,000 miles, and is 3,400 miles in diameter. Callisto revolves in 16d., 8h., 5m., and 7s., is distant 1,193,000 miles, and is 2,900 miles in diameter.

The satellites revolve in orbits whose plane is almost in the plane of Jupiter's equator, and they frequently pass between the planet and the earth. The satellites are not equally brilliant, which has given rise to the opinion that they may be more or less obscured by dark spots.

Transits.—During their transits across Jupiter's face, the first satellite appears to have a grayish tint; the second looks like a bright spot; the third as a dark brown spot; and the fourth appears nearly black.

Have they Atmospheres?—The third and fourth satellites are thought to have no atmosphere, the first a very tenuous one, but the second, owing to its high reflection and the indistinctness of its shadow, is regarded as having a very dense atmosphere.

The Flight of Light.—The velocity of light has been measured through means of the eclipses of Jupiter's satellites. This velocity is computed at 185,000 miles a second. When the earth is near Jupiter the eclipse is noticed to occur sooner than the calculated average time; and when the earth is far from Jupiter the eclipse is perceived to occur later than the predicted average time. This is because the light-flash is not instantaneous, but occupies time in its flight.

SATURN.

Saturn follows Jupiter in the order of distance from the sun. Saturn is the outermost of the five Planets known to the ancients, and its orbit marked the frontier of the old system of worlds.

Its Color.—Saturn appears to the unaided eye as a star of the first magnitude, and shines with a dingy, yellowish light.

Its Year.—The Planet circles its great path in 10,759.24 days, or in about 29½ years.

Orbital Velocity.—Its average velocity around its orbit is 5.96 miles a second.

Apparent Motion.—Owing to its great distance its apparent motion among the stars is slow, passing over only about twelve degrees in a year. Still, its motion was well known to the ancients.

Distance.—Its mean distance from the sun is about 887,130,000 miles.

Diameter.—Saturn's mean diameter is about 71,000 miles.

Shape.—Saturn is very much flattened at the poles, its equatorial being to its polar diameter in the ratio of about 10 to 9. This departure from the spherical shape is attributed to its high rate of rotary speed. It rotates with about twice the axial velocity of the earth, and makes a complete revolution in 10h., 14m., and 24s.

Density.—Saturn has a lower specific gravity than even Jupiter. Its density is 0.75 that of water, and 0.1325 that of the earth. Thus it would easily float in water.

Its Mass.—The mass of the Planet has been computed, from the control it exercises over its satellites, to be more than eighty times the earth's.

Volume.—Its volume is about 700 times that of the earth.

Internal Heat.—It is concluded, from its very low specific gravity, that Saturn still retains much of its primitive heat, and is, indeed, much hotter even than Jupiter.

Belts.—Faint belts of delicate tints of brown and blue are visible on the globe of Saturn. These belts change their aspect from time to time, but, owing to the Planet's enormous distance, changes cannot be either well noticed or easily followed.

Inclination of Orbit.—The orbit of Saturn is inclined to the ecliptic by 2° 29′ 40″, and departs a little more from the circular form than does that of Jupiter. The inclination of Saturn's axis to the plane of its path is about 63° 10′ 32″. The Planet's equator is much more oblique to the plane of its orbit than is the case with the earth. This obliquity amounts to about 31°, and so the Planet's seasons are much more varied than with us.

Spectrum.—The spectrum of Saturn is essentially similar to that of Jupiter, showing the aqueous absorption line, and the "red star" one.

Saturn's Rings.—Saturn has a wonderful ring system, consisting of three main divisions. There is the gray outer ring, the middle bright ring, and the interior dusky or "crape" ring. Parts of the middle ring are brighter than the Planet. With a powerful telescope and a good position of Saturn a very faint division is noticed in the outer gray ring. The very best time to observe Saturn's rings is when the Planet is so situated that the plane of the rings, when produced, will pass between the earth and the sun. This occurrence, however, is a rarity, and not until

1907 will the very best opportunity of this kind be offered.

The Crape-Ring.—Professor Bond discovered the third, or crape-ring, in 1850. This crape-ring is somewhat transparent, the Planet being obscurely visible through it.

Many observers are of the opinion that this inner ring has, since its discovery, been growing inward and becoming more and more visible, and, indeed, that the whole ring-system is gradually widening.

Saturn not self-luminous.—The rings cast their shadow on the Planet, and the Planet on the rings, showing that both rings and Planet shine by reflected sunlight.

Mechanism of Rings.—The safest mechanical opinion concerning the mechanism of the rings is that they consist of a vast school of small meteoric bodies revolving in separate orbits around the primary. This satellite theory was first suggested by Roberval, in the seventeenth century; afterwards by Jacques Cassini, in 1715, and later still by Wright, in 1750. James Clerk Maxwell advocated it in 1857, in an essay which won the Adams Prize of that year. Advocates of the nebular hypothesis see in the Saturnian system an early stage in the development of all the planetary worlds.

Inclination of Rings.—The plane of the rings is inclined to the plane of Saturn's orbit by 27°. When the edge of the ring is turned eyewise or sunwards, owing to its great thinness, it is invisible except to the strongest glasses, and even with their aid appears only as a very fine line of light.

Dimensions of Rings.—Guillemin gives the following table of the dimensions of the rings:

Diameter of outer ring	173,500	miles.
Breadth of outer ring	10,000	"
Diameter of middle ring	150,000	"
Breadth of middle ring	18,300	"
Distance separating outer and middle ring	1,750	"
Inner diameter of middle ring	113,400	"
Breadth of crape-ring	9,000	"
Distance of crape-ring from Planet	10,150	"
Entire breadth of ring-system	39,050	"
Thickness of rings probably not more than	100	"

The crape-ring joins the middle ring.

Observers have disagreed more concerning the behavior of Saturn and his system than about that of all the other Planets besides. Variations in the divisions of the outer ring, in the aspect of the crape-ring, and in the position of the ring-system have been repeatedly announced, and as often denied. The fluctuating character of our atmosphere, even when steadiest, is probably the chief cause of the discrepancies. The very high telescopic power required by the Saturnian system both gives the Planet a faint appearance, by spreading out its light, and magnifies the air-waviness, rendering the perception of delicate minutiæ equivocal.

Spectrum of Rings.—The spectrum of the rings shows much less atmospheric effect than does that of the Planet.

Satellites.—The following is a table of the elements of the eight satellites of Saturn:

Name.	*Mean Distance from Planet's Centre.*	*Sidereal Periodic Time.* D.	H.	M.	S.	*Discovery.*
Mimas	118,000 miles	0	2	37	15.9	W. Herschel, Sept. 17, 1789.
Enceladus	152,000 "	1	28	53	6.8	W. Herschel, Aug. 28, 1789.
Tethys	188,000 "	1	21	18	26	J. D. Cassini, Mar. 21, 1684.
Dione	241,000 "	2	17	41	9	J. D. Cassini, Mar. 21, 1684.
Rhea	337,000 "	4	12	25	11	J. D. Cassini, Dec. 23, 1672.
Titan	781,000 "	15	22	41	25	C. Huyghens, Mar 25, 1655.
Hyperion	946,000 "	21	7	7	41	Bond-Lassell, Sept. 19, 1848.
Japetus	2,280,000 "	79	7	53	40	J. D. Cassini, Oct. 25, 1671.

The orbits of all these satellites, except that of Japetus, lie almost in the plane of the rings. The path of Japetus is inclined by about 8° 16′ to this plane.

Titan has been measured and its diameter computed at more than half that of the earth, and so its volume is about nine times that of the Moon. Titan is the largest of the satellites, and is plainly visible in a small glass. Japetus is also easily seen; but Rhea, Dione, and Tethys demand strong, and Mimas and Hyperion the most powerful, telescopes. Enceladus is not very difficult of observation.

Japetus varies greatly in brightness. Sometimes it is 4½ times brighter than at other times. It is thence concluded that this satellite turns the same face constantly toward the primary, and that one-half of its disc is dusky.

URANUS.

Uranus succeeds Saturn in the order of distance from the sun. This Planet was unknown to the ancients.

Discovery.—It was discovered by William Herschel on the night of the 13th of March, 1781, while examining some stars in the constellation of the Twins.

Herschel was a keen observer, and as soon as the new Planet came into the field of view of his not very great telescope, he immediately discovered its minute disc, and knew that it was not a star. He at first thought it to be a comet; but the mathematicians Lexell and La Place soon announced the newly discovered body to be a Planet.

Planetary Elements.—Its orbit is almost circular, and it traverses it in 30,688.39 days, or about 84 years. Its average distance from the sun is 1,784,000,000 miles.

Uranus shines as a star of the fifth magnitude, and is visible to the unaided eye.

In the telescope Uranus shows a small sea-green disc.

The diameter of the Planet is variously estimated at between 31,700 and 34,500 miles. Its volume is between 64 and 82 times that of the earth.

Uranus is about 15 times as heavy as the earth, while the density of the matter composing it is only one-sixth of the earth's; and so the Planet weighs very little more than an equal volume of ice.

The heat and light received from the sun upon Uranus are about the 370th of what we receive.

Its path is inclined to the ecliptic by 46′ 21″.

Markings and Rotation.—Concerning the Planet's form, rotation, and markings there is little more than disputes.

This is due to its immense distance and, consequently, small and faint disc in the very best telescopes. Young, Schiaparelli, and Schafarik have found a distinct bulge upon the Planet, lying in the plane of the orbits of its satellites, and have concluded that the Planet rotates in this same plane.

On the other hand, the markings on the Planet's disc would indicate that it rotates in a plane inclined at one-half a right angle to the plane of the paths of the satellites.

Observations made at Paris in 1884 by the brothers Henry, and at Nice in the same year by Perrotin and Thollon, indicate that the direction of the Planet's rotation makes an angle of 40° with the plane of the orbits of the satellites.

Buffham, in 1870–72, gave the time of rotation of the Planet as twelve hours.

The observations at Nice in 1884 indicate a rotation period of ten hours.

These, however, must be regarded only as clever guesses.

Spectrum.—The spectrum of Uranus is a remarkable one. The Fraunhofer lines of the solar spectrum are wanting in that of Uranus, and are replaced by six original absorption bands. One of these belongs to the blue-green line of hydrogen, and one to the "red-star line." The others are unknown.

It is concluded from this spectrum that the atmosphere of Uranus must be so highly heated as to be capable of reducing water to its elements of hydrogen and oxygen.

Satellites.—Uranus has four satellites whose existence is certainly known. William Herschel thought that he perceived at least two additional ones, but it seems that he was mistaken, and probably saw faint stars in the Planet's neighborhood.

Elements of Satellites.—W. F. Denning gives the following table of the elements of the satellites:

Names.	*Periodic Time around Primary.* D.	H.	M.	S.	*Distance from Planet.*	*Discovery.*
Ariel	2	12	29	21	123,000 miles	W. Lassell, Sept 14, 1847.
Umbriel	4	3	28	8	171,000 "	O. Struve, Oct. 8, 1847.
Titania	8	16	56	25	281,000 "	W. Herschel, Jan. 11, 1787.
Oberon	13	11	6	55	376,000 "	W. Herschel, Jan. 11, 1787.

An Extraordinary Anomaly.—The satellites revolve in an orbit whose plane is almost perpendicular to the ecliptic, or Planet's path. This is an extraordinary anomaly in the solar system. The paths of all the Planets, great and small, and of the satellites, lie almost in the plane of the ecliptic; and the motion of satellites and Planets is in the same direction, from west to east, or in a contrary one to the hands of a watch. The path of the Uranian satellites is turned away about 98° from the ecliptic, and their motion is retrograde, or from east to west.

The orbits of the Uranian satellites lie in the same plane, and their motion around the primary is the nearest approach to being circular of any other in the solar system.

NEPTUNE.

Neptune is the outermost of the known Planets.

Discovery.—It was discovered through the perturbations it occasioned in the orbit of Uranus. Mathematicians, after making allowance for all the known elements in forming the path of Uranus, still found that the observed place of the Planet departed considerably from the theoretic one. These mysterious perturbations could only be attributed to the action of an undiscovered Planet, revolving in the awful void beyond Uranus.

Two mathematicians, Leverrier and Adams, computed independently the mass and place of the disturbing body. Dr. Galle, of Berlin, by direction of Leverrier, pointed his telescope to the heavens on the night of September 23, 1846, and found the Planet within 1° of the indicated place.

It appeared, according to prediction, as an eighth magnitude star, with a tiny disc.

It was one of the greatest achievements of mathematical astronomy, and has made the names of Leverrier and Adams immortal.

Planet's Color.—The Planet's disc has a pale blue color, but owing to its great distance no markings have been discerned on it.

Planetary Elements.—The diameter of Neptune is about 35,000 miles, or more than four times that of the earth.

Its average distance from the sun is 2,795,000,000 miles, or about 30 times the earth's mean distance.

It travels in its orbit at the rate of about three miles a second, and requires 60,181.11 days, or about 165 years, to complete a circuit of it.

The inclination of its orbit to the sun's path is 1° 47′.

The volume of Neptune is nearly 105 times the earth's, and its mass 21 times that of the earth. In reference to size, Neptune is the third Planet of the system.

The density of Neptune is only one-fifth that of the earth.

Heat and Light.—The intensity of the heat and light received by Neptune is about the thousandth part of that received by us.

Axial Rotation.—Maxwell Hall, toward the end of 1883, suggested that the Planet turned on its axis in a little less than eight hours. This, however, for want of data, is considered not even a good guess.

Spectrum.—Neptune gives the feeblest indications of a spectrum analogous to that of Uranus.

Satellite.—Neptune is accompanied by a single satellite, discovered by W. Lassell seventeen days after the Planet's discovery. The satellite revolves about its primary in about 5 days and 21 hours.

Its mean distance from Neptune is about 220,000 miles.

Motion Retrograde.—The motion of this satellite around the primary is still more markedly retrograde than that even of those of Uranus. The satellite's orbit is almost turned upside down, its inclination to the ecliptic being 145° 7′.

If the motion of a single one of the great Planets had been retrograde, the destruction of our system of worlds would be a mere question of time.

New Planets.—It is strongly surmised by mathematicians that a Planet or Planets may exist beyond the path of Neptune.

Professor Forbes, of Edinburgh, from his study of the conduct of certain comet groups, has formed the opinion that they are in some unexplained way connected with the Planets. Thus, for instance, a number of comet families have their point of greatest distance from the sun close to the orbit of Jupiter, and other groups are similarly situated with respect to Neptune.

The professor has discovered that two large groups of comets have their aphelion points situated at distances respectively of 100 and 300 times the radius of the earth's orbit. He surmises that Planets may revolve at these distances from the sun.

Dr. Todd, of Washington, independently deduced from the "residual errors" of Uranus that Planets may revolve at these same precise distances.

TABLE OF THE ELEMENTS OF THE MAJOR PLANETS, AND OF THE MOON.

Name.	Periodic Time.	Mean Diameter. *Miles.*	Mean Distance from the Sun. *Miles.*	Inclination of Orbit to Ecliptic.	Time of Rotation on Axis.
Mercury...	88d.	2,990	36,000,000	7° 0′ 8″	24h.
Venus.. ..	224.7d.	7,660	67,000,000	3° 23′ 35″	23h. 21m.
Earth	365.26d.	7,926	92,500,000	....	23h. 56m. 4s.
Mars......	687d.	4,200	141,000,000	1° 51′	24h. 37m. 22.7s.
Jupiter...	4,332.6d.	85,000	482,000,000	1° 18′ 41″	9h. 55½m.
Saturn....	10,759.24d.	71,000	887,130,000	2° 29′ 40″	10h. 14m. 24s.
Uranus...	30,688.39d.	31,700 ?	1,784,000,000	46′ 21″	10h. ?
Neptune..	60,181.11d.	35,000	2,795,000,000	1° 47′	8h. ?
Moon.....	27d. 7h. 43m. 11½s.	2,160	238,793	5° 8′ 40″	27d. 7h. 43m. 11½s.

CHAPTER VIII.

ARE THE PLANETS HABITABLE?

THERE is scarcely a subject in Astronomy that opens a wilder field for speculation than this of the habitableness of the planets. In dealing with the question it will be safe to avoid dogmatism as much as possible.

Conditions of Life.—It is very difficult to determine what are the conditions absolutely necessary for life on a planet. It was always thought in the past that no animal life could subsist in the great sea-depths, the pressure of the water being so great down there as to crush the mail of the crocodile. But lately it has been discovered that animals do live in these depths, and even have organs of vision. They have been brought to the surface by dredges, but had burst open long before they reached it.

What We know of the Planets.—We must almost entirely judge of the constitution of the planets from their supposed analogy to the earth. And how limited is our knowledge even of the physical constitution of the great body of our own planet! We are actually acquainted only with the strata immediately contiguous to the earth's upper surface.

What slight knowledge we possess of the interior is gleaned from a few fissures, or the bores and shafts of miners. None of these is more than a few thousand feet in depth.

And yet we know even more of the interior of the planets than of their surface and climate. Their mass, density, weight, volume, and distance are being ascertained with ever-increasing exactness; but, notwithstanding the constant use of our great telescopes, our knowledge of the physical character of a planet's soil and atmosphere is deeply obscure.

Many circumstances that vitally influence life on the earth, such as the chemical affinities of matter on its surface, the regular forms in which its molecules combine together, how the combinations and decompositions of the elements of matter are affected by light-waves, and the effects of electricity and electro-magnetism, remain to us, in regard to the planets, as the darkest of enigmas.

It seems to be conceded that, in judging of the habitableness of a planet, its heat and light, the force of gravity or weight of bodies at its surface, and its density or consistency, must be primarily considered. But we know that there are a multitude of circumstances besides of vital moment ; such as the density and height of the atmosphere, the length of the day, the obliquity of the sun's rays. We must remember, too, that, as a supporter of animal life, the consideration ot the constitution of the atmosphere, and the proportion of deleterious gases mixed with it, are of paramount importance.

Our atmosphere is a mixture of about one-fifth oxygen and four-fifths nitrogen.

In certain countries, however, carbonic acid gas flows abundantly out of the ground, and vitiates the sweet air. In the island of Java there is a valley where the soil emits such quantities of this gas that nothing can live within its limits, and the birds that try to fly over it fall down and die. In the Pozzuolo grotto near Naples a man can walk without danger, but a dog cannot venture in without being immediately asphyxiated, owing to the inhalation of carbonic acid gas. This deadly gas is heavier than air, and remains low down near the ground, so that the man escapes its influence while the dog inhales it with fatal consequences.

What a multitude of circumstances, concerning whose existence we can but conjecture, are to be regarded in judging of the habitableness of the planets! Moreover, every great discovery puts in hazard our formed opinions, or may force us to radically change them. The eighteenth century astronomers, guided by William Herschel, religiously believed that the sun was peopled with a superior race of beings. Herschel regarded the sun as a large, lucid planet, having a cool, dark, solid globe, with a surface diversified by valleys and mountains, covered with luxuriant vegetation, and "richly stored with inhabitants."

Overhead and surrounding this solid globe was a luminous solar aurora, thousands of miles in depth, sending forth light and heat. The surface of the great primary planet was protected from the intolerable heat and light by the intervention of a canopy of heavy clouds.

This limitless Eden enjoyed a perennial spring. The lamp of Aladdin never guided happy genii to a more wondrous abode.

The spectroscope absolutely dissipated this fabric of Herschel when it demonstrated to us the true physics of the sun.

Outer Planets.—It seems to be the conclusion of astronomy and physics, as far as our present knowledge goes, that the four outer planets are still too highly heated to be in a fit condition for the maintenance of life such as we witness it on the earth.

Their average density is very little more than that of water, Saturn's being even much less. It is, then, safe to say that they have no solid crust.

According to the testimony of the telescope, Jupiter's surface is undergoing continual changes. Heated vapors are constantly rising from the interior, then, cooling down, are thrown back into the boiling mass beneath. The most awful tempests, incomparably wilder than our fiercest tornadoes, occur in his glowing atmosphere. Jupiter seems to be, at present, in a middle state between a planet and a sun.

Saturn appears less heated than Jupiter, and its atmosphere calmer; but it is as good as demonstrated that the planet has no solid surface.

The telescope tells us little concerning Uranus and Neptune. The spectroscope seems to intimate that they have dense atmospheres. The little we do know about these planets shows them to be in a similar condition to Jupiter and Saturn.

Uranus receives from the hearth of the system only the 370th part of the light and heat that we do, and to an Uranite the sun would appear as a brilliant star, without perceptible disc.

Minor Planets.—Of the habitability of the minor planets but little need be said. Being so small, and entirely destitute of gaseous envelope, they cannot be the fitting abodes of life.

Satellites.—We may, too, safely pass by the satellites of the great planets as not being capable of sustaining the life that we know.

Our moon has neither atmosphere nor water, and is possessed of such an extraordinary climate that life as known to us could not survive a single hour upon it.

Mercury.—Mercury has a solid crust like the earth, and its density is a little greater than that of our own planet. Its orbit being very eccentric, the light and heat it receives from the sun vary from four to ten times the amount reaching us.

It rotates on its axis in about twenty-four hours, so that its day is about the same length as ours.

The length of Mercury's year is only eighty-eight days, so that its seasons succeed each other very rapidly. The time from midwinter to midsummer is only forty-four days, and in that short interval the heat of the sun increases from four to ten times the heat received by us.

There is much doubt about the existence of an atmosphere on Mercury, some contending that it has a dense one, and others, and perhaps the more trustworthy, vouching that it has none.

It is certain that an atmosphere has much to do in modifying the effects of solar heat; but it seems unreasonable to expect that any atmospheric envelope, howsoever dense, could protect life under the fearful fluctuations of the Mercurian temperature.

The mass of Mercury is about the one-twenty-fourth of that of the earth, and a pound weight with us would be only seven ounces on Mercury.

The axis of this planet is much inclined from a perpendicular to its orbital plane, and this adds greatly to the suddenness and violence of the vicissitudes of its temperature.

Venus.—Venus has a dense atmosphere, heavily charged with moisture. This planet is similar to the earth in many particulars. Their size, mass, and density are nearly equal. The length of their day is about the same.

Venus, however, owing to its greater proximity to the central orb, receives twice as much heat and light as we do.

The weight of bodies on its surface does not differ materially from what it would be upon the earth's surface.

There are, however, two respects in which Venus differs widely from the earth, and which have a vital effect on its habitability. These are, the length of its year, and the obliquity of its equator to its orbital path.

The year of Venus is about 224 of our days, and its equator is inclined to its path by an angle of 53° 11′ 26″.

The obliquity of the earth's equator to the ecliptic is only 23½°. It is this obliquity that produces the seasons on the earth. If this obliquity had been greater, the change of seasons would be more decided; and if less, the change would be less marked.

Again, on the earth the seasons are divided by intervals of about ninety days, whereas on Venus, the year being 224 days, the seasons are separated by only fifty-six days.

The Cytherean seasons must change with appalling suddenness and violence. To live through the vicissitudes of this Cytherean climate would require a species of animals of iron constitution.

Venus is, moreover, covered with a cloud-mantle, in which there is scarcely ever a rift, and which indicates a continuous rain-fall upon the planet.

Under these circumstances, Venus may be the abode of an abundant and rich vegetation, but it is almost too much to expect that animals could survive a perpetual down-pour of rain.

This seems to be the safest conclusion from our present meagre data. It must be said, too, that these data are shrouded in much uncertainty. The nature of the cloud-canopy and the amount of equatorial obliquity are involved in some doubt.

Mars.—Of all the planetary bodies Mars bears the closest analogy to the earth, and seems to give all telescopic and spectroscopic probabilities of conditions favorable to life as we know it. And we are better acquainted with Mars than with any other planet, on account of its favorable position, and the freedom of its atmosphere from clouds and vapors.

Still, these neighboring planets differ radically in a number of minor details which, taken together, might be fatal to the condition of life.

The orbit of the planet is very eccentric. Mars is sometimes 26,000,000 miles nearer to the sun than at other times. The length of its year is 687 days. Its equator is inclined to its path by 27°, so that the change of its seasons is much more marked than with us.

The mass of Mars is little more than an eighth of the earth's, and the force of gravity on its surface is less than one-half of what it is on the earth.

Its atmosphere is much thinner than ours, and, instead of weighing fifteen pounds on the square inch, weighs only two and a quarter pounds.

Its day is a little longer than ours. Its surface is about equally divided between land and water.

Mars, as a world, unmistakably shows the signs of age. It appears much older than the earth.

It is thought that, as in the case of the moon, the air and water have, in a great measure, been absorbed into the planet's interior.

The continents of Mars everywhere interlace with arms of the sea, indicating that the land and water levels scarcely differ; and Schiaparelli and others hold that their outlines are not constant. The encroachments of dusky upon bright tints suggest vast inundations, occasioned by the melting during summer of the immense quantities of snow and ice gathered at the poles during the long winter, and completely deluging the entire surface of the planet.

With its floods covering the whole surface, its atmosphere rarer than that which oppresses the respiration of the traveller on the tops of our loftiest mountains, and its extreme variations of temperature, it is scarcely credible that man could live just now in the Martian world.

Mars receives from the sun but between one-half and one-third the amount of light and heat that we do. Owing to this and to the peculiarity of its seasons, arising from the obliquity of its equator to the plane of its orbital path, the cold on this planet must be truly enormous. Linnæus is of the opinion that the Martian year of 687 days is utterly destructive of vegetation as known to us.

Whilst Venus looks to be a planet in its youth, Mars seems to have reached the sere and yellow leaf.

CHAPTER IX.

COMETS.

Aspect.—We come now to treat of a wayward branch of the great solar family. The planets move around the sun in paths almost circular; their orbits lie nearly in the same plane, and all move in the same direction.

The cometary paths, on the contrary, depart widely from the circular form, are inclined at all angles to the ecliptic, and cometary motion is in every conceivable direction.

Ordinarily a Comet consists of three parts: the nucleus, the coma, and the tail. The nucleus and coma compose the head of the Comet. The nucleus is the dense central part of the head that looks brightest to the eye. The coma is a fringe of foggy appearance surrounding the brilliant nucleus.

The tail of the Comet is the luminous train stretching away from the nucleus. The tail is a continuation of the coma, is of a milky appearance, widens and grows faint as it recedes from the head, and invariably flows away from the sun.

Some Comets are without tails; others have no nucleus, and others again neither tail nor nucleus. These latter look like an irregular patch of vapor in the sky.

Obey Gravitation.—Edmund Halley was the first to demonstrate that Comets obey at least one great law of the solar system, that of gravitation.

Halley computed the orbit of the great Comet of 1682, and predicted that it would return after intervals of about seventy-six years.

By measuring the Comet's angular velocity, and noting its place among the stars at different intervals, he was able to trace its path, and compute the time consumed in traversing it. Having found the elements of its orbit, and the periodicity of its visits to the sun, Halley followed the Comet back to the birth of Mithridates, 130 B.C.

Halley predicted that it would return in 1758, or the beginning of 1759. Clairaut and Lalande calculated that the Comet would be retarded one hundred days through the influence of Saturn, and five hundred and eighteen days through that of Jupiter, beyond the time of its return fixed by Halley. They accordingly placed the date of its nearest approach to the sun as the 13th of April, 1759, noting that their result might be inaccurate by a month either way.

The Comet actually reached its perihelion on the 12th of March, 1759.

This computation must be regarded as a marvel of success when it is recollected that Uranus and Neptune were still undiscovered, and so no account taken of their perturbing effects on the Comet's orbit.

Halley's Comet is expected to reappear in the year 1910.

Planetary Comets.—There are about a dozen Comets, besides Halley's, moving in elliptical orbits whose periods have been accurately ascertained. They are known as Periodic Comets, or "Comets of short period," and revolve around the sun from west to east similarly to the planets.

Their orbits are not greatly inclined to the common track of the planets, and are much less eccentric than those of Comets generally.

Encke's Comet, having a period of 3.3 years; Biela's, 6.6 years; Faye's, 7.4 years; Brorsen's, 5.6 years; D'Arrest's, 6.4 years; Winnecke's, 5.6 years; Tuttle's, 13.8 years; Tempel's, 6 years; Halley's, 76 years, are the principal periodic or "planetary" Comets.

All these, except Halley's, are telescopic Comets, invisible to the unaided eye, and remarkable for their short appendage and feeble nucleus.

Comets are said to consume themselves in producing their tails. The substance ejected into the tail is lost to the central body.

The sun causes the flow of matter from the head to the tail, and hence the more visits a Comet makes to the sun's neighborhood the more rapidly it wears out and is dissipated.

The periodic Comets, consequently, owe their consumptive appearance to their frequent approach to the sun.

The "planetary" Comets have their aphelion distance in the vicinity of Jupiter or Saturn. Their destinies are controlled in great measure by these giant planets. It is surmised that these planets caught them on their first approach to the sun, and changed their orbits, making them periodic Comets, and may ultimately expel them from the system.

It is very probable that a telescopic Comet of 1770 had its orbit so radically changed by a close approach to Jupiter in 1779 as to be driven out into space.

Resisting Medium.—Encke's is the most celebrated of the planetary Comets on account of its connection with the theory of the existence of a resisting medium in space.

Encke concluded that his Comet was gradually falling upon the sun, owing to the presence of an extremely rare substance in the vicinity of the central luminary. He thought that while this medium influenced the motion of such ethereal bodies as Comets, still it was altogether too immaterial to appreciably affect planetary velocity. Also, the medium was supposed to be confined to the immediate neighborhood of the sun.

Encke calculated that his Comet traversed its orbit two and a half hours shorter each succeeding revolution.

A resisting medium would have the effect of accelerating instead of retarding a Comet's velocity, as it would shorten its path around the sun by throwing it in towards that luminary.

Against the existence of the medium it was objected that other telescopic Comets were not in the least influenced by it.

To this it was argued that Encke's approached much nearer to the sun than did the others, none of which encountered the medium.

The great Comet, however, of 1882 upset altogether Encke's theory of a resisting medium. In its passage through the sun's surroundings the Comet experienced not the slightest resistance from any source whatever. It approached to within 300,000 miles of the solar surface, and the rare substance supposed to obstruct Encke's Comet would be 2,000 times more dense at this Comet's nearest point to the sun than at the nearest point of Encke's; and if the medium existed, its influence would in this instance certainly be much more strongly felt.

The track of this Comet was followed with accuracy for a week before its perihelion, as well as for months after it. The Comet's velocity before and after it reached perihelion was compared, and the computed place after perihelion perfectly agreed with the observed place, and thus demonstrated the non-existence of a resisting medium.

Encke's Comet, August, 1835, being in the vicinity of Mercury, was utilized as a means of weighing the planet. The mass of Mercury was computed by Von Asten, from its perturbing influence on the Comet's orbit, to weigh about $\frac{1}{24}$ of the earth's.

The nebulous matter composing Comets contracts in bulk on an approach to the sun, and expands as they recede.

Mass of Comets.—The matter composing Comets is of extraordinary tenuity. The feeblest ray of light may traverse thousands of miles of cometary substance without perceptible diminution. As an indisputable instance of this, Dawes saw a star of the tenth magnitude through the very centre of a Comet on the 11th of October, 1847.

Cometary Tails not Permanent Appendages.—The tails of Comets are not really permanent appendages, but emanations, or inconceivably rapid outflows of exceedingly rare matter from the nucleus. This substance composing the tail is detached and lost to the Comet. The Comet's tail has been likened to the train of smoke flowing from the stack of a moving steamship, the form being preserved while the smoke is lost.

On no other grounds can the perihelion sweep of a Comet's tail be accounted for, as no permanent appendage millions of miles in extent could be whirled around the sun in the short space of a few hours.

Comets Short-lived.—Comets appear to be but transitory agglomerations subject to disintegration and final decay. This seems to be proven by the breaking up and disappearance of one (Biela's), and the gradual but sure waste of substance of almost all.

Spectra of Comets.—Donati, in 1864, made the first successful application of the spectroscope to the examination of Comets.

He made the experiment on Tempel's Comet, and found its spectrum to consist of three bright bands of yellow, green, and blue divided by broader dark ones. Up to this time it was thought that comets shone entirely by reflected sunlight. This spectrum showed them to be chiefly composed of glowing gas, and self-luminous.

Dr. Huggins found the cometary spectrum to be similar to that of olefiant gas ($C_2 H_4$).

Eighteen Comets whose light has been examined in the spectroscope have given what is known as the hydro-carbon spectrum, due to the presence of acetylene gas ($C_2 H_2$).

The brilliant comet of Coggia, discovered April 17, 1874, was carefully examined by Vogel, Huggins, Bredichin, and Secchi. They unanimously pronounced its spectrum that of olefiant or marsh gas (CH_4).

It had, owing to its brightness, the complete hydro-carbon spectrum, consisting of five bands of different colors. The telescopic Comets previously examined, owing to their feeble light, had given but three of these bands.

Zöllner has shown that, owing to evaporation and other changes caused by solar heat on the near approach of Comets to the sun, strong electrical excitements are occasioned in these bodies.

Comets, although principally composed of glowing gas, probably owe their light to electricity rather than incandescence.

The spectrum proper of Comets is usually accompanied by a faint continuous spectrum, due partly to reflected sunlight and partly to the heated glow of small solid particles.

How Cometary Tails are Formed.—The train of a Comet is composed of matter in a condition of great tenuity. The particles of this matter are acted upon by a force of electrical repulsion from the sun.

While the force of gravity of a body depends upon its mass, the electrical energy of attraction or repulsion depends on the extent of its surface. As the size of the particles of matter diminishes, the efficacy of the sun's electrical repulsion, compared with its gravitational attraction, on a gathering of particles increases.

If the particles become sufficiently small, the repulsion will be greater than the attraction, and the particles are repelled from the sun.

It seems that the Comet and sun are similarly electrified, and while the denser nucleus obeys the laws of solar gravitational attraction, the much lighter particles emanating from it are electrically repelled, and form the train.

To obtain this effect no greater degree of electrical excitement would be necessary in the Comet than is accorded to the earth's surface ordinarily.

Classes of Comets.—Professor Bredichin, of Moscow, divides Comets into three classes, for the individuals of each of which the repulsive force is the same. He studied the construction of thirty-six Comets, and found all to agree perfectly with his rule of division.

In the first class the sun's repellent energy is twelve times as great as its attractive power. These Comets have great long, straight trains, projected away from the nucleus at the rate of 2.8 miles per second. To this class belonged Halley's, and the Comets of 1811, 1843, and 1861.

In the second class the forces of attraction and repulsion are equal on the average. The repulsion may exceed the attraction $2\frac{1}{2}$ times, or may descend $\frac{8}{10}$ below it. In this class the initial velocity of the matter forming the tail is 984 yards a second, and the tail has a plumy appearance. To this type belonged Donati's and Coggia's Comets.

In the third class the tails are formed with a repellent force of about one-fifth that of gravity, and the initial velocity of the train-matter is 328 yards a second. The tails of this type of Comets are strongly bent, short, and brush-like.

These three classes of tails may be sometimes seen in a single Comet.

Bredichin found the substance composing the first class of trains to be hydrogen, the second hydro-carbon, and the third iron or some other metal.

It would seem that the atomic weights of these substances are inversely proportioned to the repulsive force employed in the production of the respective trains.

The truth of this theory of Bredichin has been abundantly illustrated by the appearance of five recent bright Comets.

Is Identity of Path Identity of Comets?—Groups of Comets have been perceived pursuing one another, after intervals of several years, nearly in the same track, and consequently identity of path is no longer a certain test of the identity of Comets.

Origin of Comets.—Laplace thought the ordinary form of a Comet's orbit, previous to planetary perturbation, to be that of a hyperbola, or an extremely open curve. According to this opinion Comets are foreign to the solar system, and are encountered by our system in its passage through space.

Gauss and Schiaparelli, on the contrary, proved, independently, that a Comet's ordinary path is a very eccentric ellipse, the form of a hyperbola being the consequence of planetary disturbance.

From this it is concluded, and it seems the better opinion, that before being attracted by the sun Comets formed a portion of the nebulous matter belonging to our system, sharing in its motion of translation through space, and so were relatively in a condition of repose. Comets are detached fragments of this general nebulous truck, which, straying within the circle of the sun's attraction, are drawn around him in an orbital path.

Mass of Comets.—The substance of a Comet's tail is of the most extreme tenuity, and its mass is only an affair of pounds or even ounces.

It is not known whether the nucleus is a solid body or the most dense part of a meteoric cloud. Judging by analogy from our knowledge of telescopic Comets, it is probable that the nucleus is but a cloud of solid or liquid particles.

Professor Peirce shows, however, that the Comets of 1680, 1843, and 1858 must have had a nucleus of metallic density to have lived through the ordeal they sustained in their very close passage around the sun.

From the fact that Comets have no appreciable effect in perturbing the planets it is evident that their mass must be utterly insignificant compared with the planetary masses.

The chances of an encounter between the earth and the nucleus of a Comet are so infinitesimally small that they need not be considered.

Remarkable Comets.—The most brilliant Comet of this century was probably the one discovered on February 28, 1843. At its nearest approach to the sun but an interval of 32,000 miles separated their surfaces.

The motion of the Comet at its perihelion reached

366 miles a second. This awful velocity saved it from falling into the sun, and carried it through 180° of its orbit in the short space of two hours and eleven minutes. To travel over the other half of its orbit it may require hundreds of years.

Its tail, which was slightly curved at its extremity, extended 40° along the sky. Its extent in miles has been computed at 51,000,000. This enormous appendage was whirled around from one side of the sun to the other in 131 minutes.

Owing to the action of our atmosphere the Comet appeared to have corruscations swaying like a torch in the wind.

Periods all the way from 6 to 533 years were assigned to it. The reason of the great discrepancy was the insufficiency of data available for making the estimate.

Donati's.—Giambattista Donati discovered the Comet called after him on the 2d of June, 1858. Its tail stretched at its best in a graceful curve over more than a third part of the visible heavens. Its extent in miles was 54,000,000.

On September 17 a secondary tail was developed in the form of a straight, narrow ray, tangent to the curve of the primary, and extending to a still greater distance from the head. The visibility of the second tail continued during three weeks, and a portion of the time it appeared duplicated.

Bond estimated the diameter of the nucleus at less than 500 miles.

Seven separate envelopes were detached from the nebulous mass surrounding the nucleus, and after rising successively toward the sun fell backwards to be assimilated with the train.

On the 2d of October the nucleus outshone Arcturus, the second brightest gem of the northern heavens.

The Comet's orbit is a very eccentric ellipse, its perihelion lying inside the orbit of Venus, and its aphelion distance is 5½ times the diameter of Neptune's orbit. It requires 2,000 years to traverse its path, and the Comet's motion is retrograde, or contrary to that of the planets.

Comet of 1861.—The great comet of 1861 made its nearest approach to the sun on June 11 of that year. This Comet was noticeable for the number and complexity of the envelopes surrounding its head.

Its brightness was inferior to that of Donati's, but its tail had an extraordinary length, stretching over an arc of the heavens of 118°.

It makes a revolution of its elliptical orbit in 409½ years.

A most interesting incident connected with this Comet is that the earth passed through its tail on June 30, 1861. On that occasion our planet was immersed in cometary matter to a depth of 300,000 miles.

The collision produced not the slightest perceptible effect.

Tebbutt's Comet.—Mr. John Tebbutt, of New South Wales, discovered the Comet called by his name on the 22d of May, 1881. This Comet passed the sun on the 16th of June at a distance of about 68,000,000 of miles.

On June 24, and a few nights following, it was a most brilliant object, and outshone every star in the sky.

Its tail was plumed similar to Donati's, and it belonged to the same type as that great Comet.

The first successful attempt to measure cometary refraction was made through this Comet.

It was the first Comet, too, of which a satisfactory photograph was obtained. The substitution of dry gelatine for wet collodion, just introduced at that time, greatly increased the sensitiveness of the photographer's plates.

Janssen obtained a good photograph of the Comet from half an hour's exposure.

Dr. Huggins succeeded by chemical process in rendering visible the invisible portion of the spectrum of this Comet, and the result still further established the presence of the carbon compounds in Comets.

Comet of 1882.—A great Comet was discovered at Rio Janeiro, September 11, 1882. The Comet attained such brilliancy on the 18th of September that it could be seen in day-time in a clear sky all over the world.

It was the brightest Comet since 1843, and was visible to the unaided eye in daylight during three days.

The course of this Comet was diligently watched by astronomers, who followed it with their telescopes to a distance of 470,000,000 of miles from the earth.

It moves in a very elongated ellipse, and traverses its orbit in about 843 years. Its tail reached to a distance of 200,000,000 of miles from the head.

After its passage around the sun the Comet gave evidence of breaking up. Its nucleus separated into five parts, and in its retreat from the sun the Comet appeared to leave fragments all along its track.

August and July seem to be the months of the year most prolific in Comets, and May has on the average the least number.

The majority of Comet discoveries have been made in the vicinity of the sun; and this is but reasonable, since the sun is the focus of cometary motions. The western horizon, after sundown, and the eastern horizon, before dawn, are the most likely places to discover Comets.

CHAPTER X.

SHOOTING-STARS.

Cause of the Phenomena.—Myriads upon myriads of particles of loose matter are circling within the planetary spaces in regular orbits around the sun. These particles are moving in every conceivable direction, but nearly always in the path of a comet. Indeed, they are regarded by astronomers as cometary *debris.*

The earth sweeps along its path at an average rate of eighteen miles a second, and in its rapid progress is incessantly encountering these flying particles.

The velocity with which the particles enter our atmosphere is the resultant of their own and the earth's motion. When moving in opposite directions this resultant is the sum, and in the same direction the difference, of their respective velocities.

The average speed with which these tiny bodies strike the higher portions of our air is computed at thirty-five miles a second.

The very rarest region of our upper atmosphere offers enormous resistance to bodies travelling through it with this awful rapidity, and the friction of their passage generates an intense degree of heat.

This glowing heat renders the particles luminous while it consumes them. The flight of the burning particles through the air occasions the phenomena of Shooting-Stars or Meteors.

Heat of Meteors.—The amount of heat produced by the atmospheric resistance has been calculated on mechanical principles. It is found by experiment that the temperature of a body moving through the air rises one degree Fahrenheit when the rate of speed is one hundred and twenty-five feet a second. Friction develops heat in bodies passing through the air in proportion to the square of the velocity.

Hence, particles striking the atmosphere with a velocity of thirty-five miles a second are heated beyond two million degrees Fahrenheit.

Are Shooting-Stars Dangerous?—The earth encounters annually millions upon millions of these tiny particles, and tiny as they are, still their prodigious speed gives them the momentum of a cannon-ball. The atmosphere, however, consumes them, and thus actually affords us a better protection against them than could a shield of steel armor many feet in thickness.

These cosmic atoms become luminous at an average atmospheric height of seventy miles, and are volatilized or completely dissipated into vapor before descending to a height of fifty miles.

Meteoric Showers.—Halley was the first to hold the opinion that Shooting-Stars have a cosmical origin.

Chladni, in 1794, taught that space is filled with small circulating atoms which, becoming ignited by the friction of their rapid passage through our atmosphere, appear as Shooting-Stars.

Occasionally Shooting-Stars fall in enormous showers and produce thrilling spectacles. The particles themselves through whose combustion in the air the meteor showers are produced are called meteoroids.

The Leonids of November.—A great shower of Shooting-Stars fell upon the earth on the night of November 12, 1833. They fell in an incessant tempest for the space of nine hours, visible to the whole of North America, and with a frequency computed at half that of the flakes in a snow-storm.

The meteors all appeared to come from the same point in the heavens, the star Mu, in the constellation of the Lion.

This star is called the radiant, or vanishing point, of these November meteors, because they appeared to all spring from the particular part of the sky occupied by the star, and thence flew off in every direction.

The earth's course just then was straight toward Leo, and the meteors entered the atmosphere from the direction of the star Mu. And as Leo, with the advance of night, travelled up the sky from east to west, so the radiant point of the meteors travelled westwardly with it.

The great November shower is known as the "Leonids," from having its radiant in the constellation of Leo.

Path of the Leonids.—This great November shower has a periodicity. Indeed, the meteoroids were found by Olmstead, Olbers, Schiaparelli, Newton, and Adams to be travelling in an elliptical orbit around the sun, having their aphelion distance beyond the orbit of Uranus, and crossing the earth's orbit near their perihelion.

On the night of November 12 the earth crosses the path of the meteoroids.

The meteoric shoal completes a revolution of its orbit in 33.27 years. Consequently, about three times in a century the great swarm crosses the track of the earth.

History of the Leonids.—Professor Newton, of Yale College, traced the November meteors, or Leonids, back to the year 902 A.D., the date of their first recorded appearance. The shower has since reappeared twenty-nine times.

He predicted their return on the night of November

13, 1866. His prediction was accurately fulfilled; the shower appearing this time, however, in Europe instead of America.

They appeared in America in November of the year following, 1867, the American hemisphere being then in front.

These splendid displays drew the attention of astronomers very forcibly to the subject of meteors.

Schiaparelli on Meteoroids.—Schiaparelli gave as the result of his observations that meteoroids travel around the sun in very eccentric orbits resembling those of comets; that meteoroids move in all possible directions, and their orbits are at all inclinations to the plane of the ecliptic; and that, similarly as comets, meteoroids have been drawn into our neighborhood by the sun, and frequently held there by the attraction of some great planet.

The Perseids—Schiaparelli first announced that the August meteoroids travel in the same path with Comet III., 1862. The great August showers fall between the 9th and 11th of the month, and are called the "Perseids," from the fact that their radiant is situated in the constellation of Perseus.

In 1867 Leverrier, Peters, Adams, and other mathematicians demonstrated that the path of the November meteoroids corresponds exactly with the orbit of Tempel's comet, or, more technically, Comet I., 1866.

The meteoroids follow precisely in the wake of the comet.

The Lyrids.—About the same time Weiss, of Vienna, showed the identity of the path of Comet I., 1861, with that of a meteoric shower recurring on April 20, and known as the "Lyrids."

The Andromedes.—He also demonstrated that the

"Andromedes," or meteoroids of November 27, are travelling in the track of Biela's comet, or Comet III., 1852.

There are other showers travelling in the paths of comets, such as the Geminids, Orionids, etc.

Professor Alexander S. Herschel has shown that the orbits of seventy-six meteoric showers coincide with those of comets.

Three Great Showers.—There are, however, only three great showers: the Leonids, Andromedes, and Perseids.

Tempel's Comet—Tempel's is a telescopic comet, supposed to have been captured by the planet Uranus, and brought into our system in the year 126 of the Christian era.

The meteoric or waste material following in the path of this comet is spread out over about one-tenth of the whole orbit.

When Uranus caught the swarm it changed the speed of the particles by attracting them unequally, drawing the near ones more forcibly than the more distant. Accordingly, in time, owing to their different velocities, the particles will extend along the whole orbit, and we will have displays of equal splendor every 12th of November.

This is actually the case as regards the meteors of the 9th of August, or the Perseids.

On every 9th of August there is an equally remarkable meteoric shower.

We cannot Escape the Leonids.—The great November swarm is so extensive that, though travelling at the rate of twenty-six miles a second, it requires more than a year to pass a single point of its orbit, and on its successive visits to our vicinity can never escape encountering the earth; and so we must necessarily have the superb showers of the Leonids at intervals of 33.27 years.

Comet III., 1862.—The comet to which the Perseids belong, Comet III., 1862, is supposed to have been much longer in our system than Tempel's, and, accordingly, the particles following it are spread out along the whole length of the orbit.

Biela's Comet.—In 1867 Weiss, D'Arrest, and Galle demonstrated that Biela's comet had broken up into the meteoric swarm of November 27, or the Andromedes.

The Andromedes have their radiant in the star Gamma, of the constellation of Andromeda.

The Speed of Meteors.—The Leonids move in a direction diametrically opposite to the earth's course, and so we rush to meet them.

They travel with a rapidity of twenty-six miles a second, and, the earth's velocity being eighteen miles, the Leonids encounter our atmosphere at a rate of forty-four miles a second.

The Andromedes, on the contrary, journey in the same direction as the earth, but with much greater speed, and so overtake us, striking the air with a velocity of twelve miles a second. The Leonids, consequently, make a much more magnificent spectacle than the Andromedes.

None of the particles of the great showers have ever been noticed to reach the earth's surface. It is probable that the largest of them do not exceed in size a canary-seed, and are all entirely consumed at an average height of fifty miles.

Fireballs or Bolides.—Fireballs, or bolides, are classed with meteors, and distinguished from the ordinary shower only by their greater size.

The fireball has an apparent diameter, while the common meteor is but a luminous point.

Fireballs have long, luminous trains, a slow motion comparatively, and occasionally explode with a loud detonation.

Fireballs are rare, a few of them usually accompanying the great showers. They appear, too, occasionally apart from the showers.

A Brilliant Fireball.—W. F. Denning saw, on the night of August 13, 1888 (11 h., 33 m., G. M. T.), a brilliant fireball, furnished by the Perseid shower. It flashed like vivid lightning, and left a streak for three minutes.

This great fireball appeared over Yorkshire, and fell from the height of seventy-eight to that of forty-seven miles. Its luminous train was eighteen miles long, and appeared at heights of fifty-nine to forty-seven miles.

Meteorolites or Meteorites.—Meteorites are the solid masses that fall to the earth's surface from space, and are usually either stone-falls or iron-falls.

Stone-falls.—The stone-falls have been frequent since the first authentic shower that fell, as told by Livy, on Mount Alban, near Rome, in the year 654 B.C.

Taking the whole earth, the annual stone-falls may be counted by the hundreds.

Iron-falls.—The iron-falls are much rarer than the stone-falls.

Stone-falls are called aërolites, and iron-falls aërosiderites or siderites.

Composition.—The elements of both stone-falls and iron-falls are not unknown to the earth, and we are familiar, too, with the manner in which they are found chemically combined in these masses.

Stony meteorites, though containing many ingredients, may be said to be principally composed of nickel, cobalt, iron, and phosphorus.

The chief constituent of the iron meteorites is an alloy of iron and nickel. Masses of this alloy, exactly as it is found in the siderite, have been vomited from the earth's interior.

Aerosiderolites.—Besides the stone-falls and iron-falls, however, there are other types of meteorites of an intermediate structure and called aërosiderolites.

Behavior and Aspect.—The fall of the meteorites is accompanied by a sound much louder than the most violent thunder.

These bodies do not fall vertically, but at long range, and during the night hours are intensely luminous.

Meteorites are in nowise connected with comets.

Structure.—They are usually of a rounded form or appear as fragments of what was primitively round.

The meteorite is mostly covered with a glaze, formed by the fusion of its own substance. The heat occasioned by atmospheric friction produces this fusion.

Meteorites range in size from ounces to tons. When meteorites strike the denser portion of the air they generally explode and fall to the earth in a small shower of fragments.

Cause of Explosion.—These bodies come from the region beyond our atmosphere, the average temperature of which is estimated at 400° Fahrenheit below zero (mercury freezes at 39° below).

While the surface of the meteorite is intensely heated, the interior is cold beyond conception.

It is probably due partly to this difference in temperature, and partly to the concussion of the air caused by their rapid motion, that the meteorites so frequently explode.

Origin of Meteorites.—The little that can be said concerning the origin of meteorites is of the most uncertain character. Every theory that has yet been proposed is fraught with almost insuperable difficulties. The moon, planets, planetoids, the sun, interstellar space, and the earth itself have been variously suggested as their source.

The Terrestrial Theory.—Those who attribute their parentage to the earth contend, and justly, that bodies expelled from terrestrial volcanoes with a velocity sufficient to carry them beyond its attraction would circle around the sun in orbits necessarily intersecting our planet's path at their point of first departure.

It would often happen that the earth would just arrive at that part of its orbit when these bodies were careering by, and so encounter and catch them.

A Difficulty.—To drive a body beyond the sphere of its attraction the earth would have to impart to it an initial velocity of six miles a second. This is called the critical velocity for the earth, and is so entirely enormous that we have no record of volcanic force capable of producing even an approach to it, although the explosion which occurred at Krakatao, at five minutes past ten on the 27th of August, 1883, was heard, according to official evidence, at a distance of eighteen hundred miles, and the air-wave injured buildings two hundred miles away.

In answer to the difficulty, however, the advocates of the terrestrial origin of meteorites say that the earth when younger had much greater volcanic vigor than it now possesses.

Mineralogists seem to regard their origin as volcanic;

but where the volcanoes are located is the kernel of the difficulty.

The six months, July to December, have two and one-half times more meteoric apparitions than the six months from January to June.

Meteors are usually more numerous in autumn than in spring, and in the morning than in the evening hours.

The hourly average is about 12 meteors for the whole year. Before midnight the hourly average is 9, and 15 in the morning.

The highest rate of apparition is reached about three o'clock A.M.

Telescopic meteors are much more abundant than those visible to the unaided eye. The proportion is stated on good authority to be as high as forty to one.

LIST OF PRINCIPAL METEORIC SHOWERS VISIBLE DURING THE YEAR.

Time of Principal Display.	Approximate Star.	Notes.
January 1–4....	β Boötes.....	Annual.
March 3–5.....	β Leonis.....	Large meteors.
April 17–20....	α Lyræ......	Comet I., 1861.
April 29–May 2.	α Aquarii....	Fine meteors.
July 23–25.....	β Persei.....	Probably Comet of 1764.
August 9–11...	η Persei.....	Annual.
September 4–9.	ε Persei......	Fine display.
October 17–20..	ν Orionis....	Annual.
November 1–5..	ε Arietis.....	
November 12–14.	γ Leonis.....	Annual: Comet I., 1866.
November 27...	γ Andromedæ.	Annual: Biela's Comet.
December 8–13.	α Geminorum.	Annual.

CHAPTER XI.

THE ZODIACAL LIGHT.

Aspect.—The Zodiacal Light is the great lens-shaped mass of light which appears in the West in the evening, shortly after sunset; and in the East in the morning, before dawn.

It is of a pearly glow, and is seen to spread over the part of the sky in the immediate vicinity of the point where the sun has disappeared, or is about to reappear. It is brightest at the centre, and its lustre gradually fades toward the exterior. Indeed, the light from about the edges is so feeble that it is frequently difficult to detect where it begins, and, consequently, the limits of this spindle of light seem irregular and poorly defined.

The sun is situated at the centre of this lenticular spectacle.

The phenomenon is still an enigma, and its conduct at times is very mysterious.

It is not Twilight.—It can be easily distinguished from twilight in this, that the latter extends broadly along the horizon and reaches but a short distance up the sky.

The Zodiacal Light, on the contrary, is a narrow beam, steeply inclined to the horizon, and extending up the heavens as high ordinarily as 50°, and rarely even as 100°.

Whence its Name.—The beam is usually inclined to the horizon at an angle of 60° or 70° in our latitude, and is directed along the zodiac toward a point southwest of the zenith; and hence its name of Zodiacal Light.

Arago and others were of the opinion that its color, especially toward the base, is inclined to yellow or red.

Some observers say that the direction of the axis of this pyramid of light coincides with the solar equator; and others, with the plane of the earth's orbit, or ecliptic.

Its Changing Aspect.—The apparent place of the light varies with the inclination of the ecliptic to the horizon, and its apparent lustre depends on the season.

Its light is brightest when the ecliptic is most oblique, so that in northern latitudes it is most favorably seen in the evening in February and March, and in the morning in September and October.

Its Lustre.—The Zodiacal Light, in its brightest parts, far surpasses in lustre the most brilliant portions of the Milky Way.

Toward the Tropics it increases in intensity and height, and is visible all the year round.

Humboldt says that its lustre in Mexico and on the table-lands of Quito is very remarkable, and far exceeds even that of the portion of the Galaxy between the Eagle and Swan.

Zodiacal Cone.—This light is also called the Zodiacal Cone, from its triangular, pyramidal, or conical form, and to distinguish it, too, from the Zodiacal Band and the Gegenschein, or Counter Glow.

Zodiacal Band.—The Zodiacal Band is much feebler than the Zodiacal Cone, of which it is a continuation, and extends along the whole zodiacal road from horizon to horizon.

The Zodiacal Band is one of the faintest objects in the heavens; its lustre is much below the dimmest portions of the Milky Way, and demands the keenest vision to discern it.

This band grows dimmer as it advances up the sky away from the sun, until the opposite horizon is almost attained, when its lustre again greatly increases.

Gegenschein, or Counter Glow.—This bright part of the Zodiacal Band, near the horizon on the side of the heavens away from the sun's place, is called the Gegenschein, or Counter Glow.

Not Atmospheric.—The Zodiacal Light cannot belong to our atmosphere, since it shares in the diurnal motion of the heavens, is visible in regions of the earth widely apart, and is almost invariably inclined along the ecliptic.

Not a Solar Atmosphere.—It cannot be a solar atmosphere, since Laplace has demonstrated mathematically that no envelope sharing in the sun's axial rotation can extend farther from his surface than $\frac{9}{20}$ of the mean distance of Mercury, and this lenticular light reaches out sometimes even beyond the earth's orbit.

What is It ?—Childrey was the first to observe this phenomenon, between 1658 and 1661; and Dominicus Cassini, 1683, to determine its relations in space.

Humboldt was of the opinion that the phenomenon is probably due to the existence of a very compressed annulus of nebulous matter, revolving freely in space between the orbits of Venus and Mars, and capable of reflecting sunlight.

Laplace considered it a zone of vapor, thrown off by the sun when in process of condensation from its primitive condition to its present viscous consistency.

Other astronomers have looked upon it as an extension of the solar corona.

Others, again, as a flattened nebulous ring, surrounding the sun at some distance.

Against this it is argued that the distance from the summit of the cone to its base is frequently observed to change. This change, however, in case the phenomenon is regarded as a luminous ring, may be accounted for by supposing its form to be elliptical, or, if circular, that the sun is not in the centre.

Most recent Theory.—The most recent theory concerning this luminous spindle is that it is composed of cosmical dust, planetary refuse, cometary waste-material, and ejected vapors, circling around the sun and reflecting sunlight.

It seems to be the conclusion of science that the vast swarms of meteoroids circulating around the sun are certainly connected with the phenomenon.

The great objection against the meteoroid theory is that this light is much more dense in the plane of the ecliptic than elsewhere; and as meteoroids travel in all possible directions, there would be no sufficient reason for this increase of density.

It is also objected that there should be more variety than there actually is in the brightness and form of the light if it were produced by circulating meteoroids.

On the other hand, the presence of the Gegenschein would seem to favor the theory that this light is due to the reflection of meteoroids, as these particles would become more luminous when in opposition to the sun.

Professor Wright found that the spectrum of the phenomenon was probably that of reflected sunlight; and this would certainly favor the meteoroid hypothesis.

Professor Lewis, too, made its spectrum probably that of reflected sunlight.

It is, indeed, generally conceded that the spectrum of the Zodiacal Light is that of reflected sunlight.

The reason that there seems to be so much doubt about this spectrum is owing to the faintness of the light itself. A very wide slit must necessarily be employed to catch a sufficient amount of lustre to give a visible spectrum; and a wide slit, with the best light, impairs the definition.

It can be demonstrated that a vast swarm of particles circulating near the sun would so reflect his light as to give the appearance of the Zodiacal Light.

THE GREEK ALPHABET.

Α	α	Alpha	*Ν*	ν	Nu
Β	β	Beta	*Ξ*	ξ	Xi
Γ	γ	Gamma	*Ο*	ο	Omicron
Δ	δ	Delta	*Π*	π	Pi
Ε	ε	Epsilon	*Ρ*	ρ	Rho
Ζ	ζ	Zeta	*Σ*	ς	Sigma
Η	η	Eta	*Τ*	τ	Tau
Θ	ϑ	Theta	*Υ*	υ	Upsilon
Ι	ι	Iota	*Φ*	φ	Phi
Κ	κ	Kappa	*Χ*	χ	Chi
Λ	λ	Lambda	*Ψ*	ψ	Psi
Μ	μ	Mu	*Ω*	ω	Omega

CHAPTER XII.

THE STARRY HEAVENS.

I.—THE CONSTELLATIONS.

Their Antiquity.—From a very early antiquity the stars have been divided into groups or catasterisms, called Constellations.

Ancient astronomers called the Constellations and brightest stars after their national gods and heroes, occasionally giving them, too, the names of animals.

The most ancient reliable record, the Book of Job, mentions the Pleiades, Orion, and Arcturus. Homer alludes to the Great Bear, Boötes, Pleiades, and Orion.

Humboldt, however, is of the opinion that in the Greek sphere the stars were only gradually arranged in Constellations, since all the Greek names of stars and catasterisms were not of equal antiquity.

Modern Catalogues.—Among moderns, Bayer, in 1654, established a sidereal nomenclature, retaining the ancient names of the Constellations, and designating the individual stars according to the order of brightness by the letters of the Greek alphabet. When the Greek became exhausted he had recourse to the Roman alphabet.

As a rule the brightest star of a Constellation is called Alpha; still there are exceptions to this, the chief star being not unfrequently designated by Beta.

His method was to write the Greek letter of the star before the genitive of the Latin name of the Constellation. In this way Sirius is written in the catalogue as α Canis Majoris, and Vega, α Lyræ.

Flamsteed, in 1700, introduced a method of nomenclature in which the individuals of each Constellation are represented by numbers in the order of their right ascension.

Polaris (*α Ursæ Minoris*).—The daily eastward rotation of the earth on its axis gives the stars an apparent motion toward the west. The whole celestial sphere seems to revolve daily from east to west about one point in the north, called the Pole.

Around this point as a fixed centre all the heavenly bodies move in circles, whose sizes depend on their respective distances therefrom.

There is no star situated precisely at this pole. However, a bright lone star of the second magnitude is in its immediate neighborhood, being distant from it less than $1\frac{1}{2}°$.

This star is called Polaris, and its apparent diurnal motion is so small that to the unaided eye it appears stationary.

Polaris is easily discerned, there being no star of equal lustre within quite a distance of it. It is still more strongly marked by two stars in the Dipper pointing constantly almost directly toward it.

Ursa Major (*Great Bear*).—This Constellation is also known under the names of Dipper, Plough, and Charles' Wain.

It consists of seven chief stars, six of them being of the second magnitude, and one of the fourth.

Four of the stars, in the figure of a quadrilateral, form the cup of the dipper, and the three others the handle.

The two stars in the cup, on the side opposite to the handle, point toward Polaris, and are on this account called the "pointers."

A line joining the pointers, and continued north about four and one-half times their own distance apart, will almost touch Polaris.

The Great Bear has one hundred and thirty-eight stars visible to the unaided eye.

Cassiopeia.—This Constellation is almost directly across from the Great Bear, on the opposite side of Polaris.

These two Constellations are almost equally distant from Polaris.

The six principal stars in Cassiopeia form the appearance of a W, or reversed chair.

The Constellation has sixty-seven stars visible to the unassisted eye, two of them being of the second magnitude.

Ursa Minor *(Little Bear).*—This Constellation is situated between Cassiopeia and the Great Bear, and contains twenty-seven stars visible to the unaided eye. Polaris is its brightest gem.

Leo *(The Lion).*—The Lion is one of the conspicuous figures of the heavens, and is easily distinguished by six stars, that mark out the form of a sickle standing upright on its handle.

Regulus is the large white star in the bottom of the handle.

Denebola *(β Leonis)* shines in the eastern border of Leo. This star is of a bluish tinge, and almost as bright as Regulus.

Leo has about seventy-five stars visible to the unassisted eye, three of them being of the second magnitude.

The Sickle is almost directly overhead, or in the zenith, at 8 o'clock P.M., May 1; 10 o'clock P.M., April 1; 12 o'clock A.M., March 1; 2 o'clock A.M., February 1, and 4 o'clock A.M., January 1.

Boötes.—North-east of the Sickle, and in an extension of the curve formed by the handle of the Dipper, is found the very bright yellow star Arcturus.

This is the great brilliant that marks the Constellation of Boötes.

Boötes has eighty-five stars visible to the unaided eye.

Cancer *(The Crab)*.—This Constellation lies due west but a short distance from the Sickle, and is distinguished by a bright patch situated between two small stars.

This patch is known as the Præsepe, or Manger. The two dim stars on either end are called Aselli, or the Ass's Colts.

This silver spot in the sky is also called the Beehive.

The Manger is a weather prophet. When clearly visible it presages fine weather, but when it fades from view suddenly after unusual lustre the storm king is coming.

Corona Borealis *(Northern Crown)*.—This is a very conspicuous object in the sky, and consists of six stars in the form of a half-circle or crown.

It is but a short distance from, and almost due east of, Arcturus. Its brightest star is called Alpheta.

Orion.—Orion is certainly the most superb Constellation in the northern heavens. Four of its chief stars form a great quadrilateral, having in its centre, in a straight line and close together, three second-magnitude stars, forming the Hunter's Belt.

Two of Orion's gems are very brilliant ones indeed. These are Betelgeuse (α Orionis) and Rigel (β Orionis), the first a variable star of a rich orange hue and the second of a blue-white radiance.

Orion rejoices in the possession of about one hundred and fifteen stars visible to the unaided eye, of which four are of the second magnitude.

Orion is also familiarly known as the "Yard and Ell."

Taurus *(The Bull).*—This Constellation contains the two remarkable clusters of the Pleiades and Hyades.

The Hyades are shaped like the letter V, with the brilliant rose-red Aldebaran (α Tauri) in the upper left-hand corner.

The Pleiades are also known as the Seven Stars, although only six are discernible to ordinary vision.

The Pleiades make one of the most striking objects in the heavens, and have been celebrated in every age and country.

This cluster is called by sailors the Hen-coop.

A line from the Pleiades through Aldebaran and continued south will almost pass through the middle of Orion.

Gemini *(The Twins).*—A short distance north by west from the Bee-hive are seen two stars of the first magnitude, of almost equal brilliancy, Castor (α) and Pollux (β), which give its name to this Constellation.

Castor is white, with a tinge of green, and Pollux of a deep yellow color.

Castor is a double star, and regarded by some observers as a shade brighter than his twin brother, Pollux.

Pollux is considered by many as only of the second magnitude. Others, however, look upon Pollux as the brighter of the Twins, and rate it of the first and Castor of the second magnitude.

Pegasus.—This Constellation is a very conspicuous one from the fact that three of its own stars of the second magnitude, and one second-magnitude star of a neighboring group, form the figure of a large quadrilateral, called the Great Square of Pegasus.

About 9 o'clock P.M., on November 1; 11 o'clock P.M., October 1, and 1 o'clock on the morning of September 1, the Great Square of Pegasus is almost directly overhead.

Pegasus, Andromeda, and Perseus form a group of seven stars resembling very much the Great Bear.

Three of the seven belong to Pegasus, three to Andromeda, and one to Perseus.

This latter is Algol, a celebrated variable star.

The star in the north-east corner of the square, together with the two stars in the handle in line with it, form Andromeda.

In 1885 a great deal of attention was drawn to Andromeda, from the fact that what was supposed to be a new star suddenly shone out in line with its famous nebula. The phenomenon ceased after a few months.

From the middle star in Andromeda two faint stars run north in a line with it. Close to the north end of this line is the great nebula of Andromeda, the oldest known to Astronomy.

Piscis Australis *(Southern Fish)*.—Looking along the meridian from the Great Square of Pegasus toward the south, there is seen almost on the horizon the beautiful first-magnitude star Fomalhaut, in the Constellation Piscis Australis.

In the region between Pegasus and Fomalhaut lie the Constellations Aquarius (the Water-bearer), Capricornus (the Goat), Sagittarius (the Archer), Pisces (the Fishes), and Cetus (the Whale).

These groups, with the exception of Cetus, have no remarkable stars.

Cetus, which is south-east from Pegasus, contains the famous variable star Mira, that passes in eleven months from the second magnitude to the tenth, and back again to the second.

Canis Major (*The Great Dog*).—This Constellation contains the very gem of the skies, the peerless Sirius. This glorious star is intensely white, with a suspicion of lilac; is remarkably scintillating, and flashes like a diamond.

Sirius is also called the Dog-Star; it is south-east of Orion.

Canis Minor (*The Lesser Dog*).—In this Constellation glitters Procyon, the little Dog-Star, a magnificent golden-yellow brilliant of the first magnitude.

Sirius, Procyon, and Betelgeuse form an equilateral triangle.

Aries (the Ram), just east of the Pleiades; Minoceros (the Unicorn), south of Procyon; Hydra (the Water-Snake), south of the Sickle, have no remarkable stars.

Lepus (the Hare), and Columba (the Dove), south of Rigel, have no conspicuous stars.

Lyra *(The Harp)*.—This Constellation possesses the brilliant bluish-white star Vega, one of the brightest first-magnitude stars in the northern heavens.

A line from Arcturus through the brightest star of Corona, and continued easterly, will touch Vega.

Hercules.—This Constellation lies between Vega and Corona, and contains about one hundred and fifty-five stars visible to the unassisted eye, two of which are of the second magnitude.

The sun's journey through space is directed toward a point in Hercules.

Draco *(The Dragon)*.—The Dragon lies just north of Hercules.

Coma Berenices *(Berenice's Hair)*.—This is a beautiful and striking cluster of small stars, lying close together between the Sickle and Arcturus.

Virgo *(The Virgin).*—The pure white first-magnitude star Spica graces this Constellation.

Arcturus, Spica, and Denebola form an equilateral triangle.

The Balance (Libra), the Crow (Corvus), and the Cup (Crater) are Constellations in the neighborhood of Spica.

The Hunting Dogs (Canes Venatici), near Coma Berenices; the Little Lion (Leo Minor), north of the Sickle; and the Serpent and Ophiuchus, just south of Corona, have no conspicuous stars.

Cygnus *(The Swan).*—Alpha (α Cygni) of this Constellation is a first-magnitude star. Four other bright stars of Cygnus, together with Alpha, form a most perfect cross, lying along the Milky Way, and called the Northern Cross. It is a beautiful and striking group.

Aquila *(The Eagle).*—The Eagle has a first-magnitude star, Altair.

Altair, with Vega and α Cygni, forms an isosceles triangle.

Auriga *(The Charioteer).*—This Constellation possesses one of the greatest brilliants in the northern heavens, Capella.

Auriga is a short distance east of Perseus and north of the Pleiades.

Near Capella are three little stars forming a tiny triangle, and called the Hœdi, or Kids.

Delphinus *(The Dolphin).*—This Constellation is northeast of the Eagle, and has a cluster of four stars in the form of a lozenge, called Job's Coffin.

Scorpio *(The Scorpion).*—At 8 o'clock P.M., on July 1, Scorpio is seen just rising in the south-east. It is easily discernible by the fiery brick-red color of its first-magnitude star, Antares. This Constellation has a long, winding trail of stars, and bears a striking resemblance to a huge scorpion.

The Fox (Vulpecula) and the Arrow (Sagitta) lie between the Swan and the Eagle.

Cepheus, the Giraffe, and the Lynx are found between Cassiopeia and Polaris.

The Triangles (Triangulæ), between Aries and Andromeda; the Fly (Musica), between Aries and Perseus; the Camelopard (Camelopardalus), north of Auriga; the Sextant (Sextans), south of Regulus; the Owl (Nocta), near Virgo; Taurus Poniatowskii (the Polish Bull), near the Eagle; Scutum Sobieski (Sobieski's Shield), also near the Eagle; the Lizard (Lacerta), near the Swan, have no remarkable brilliants.

Southern Constellations.—The list of Southern Constellations embraces the Southern Cross, the Centaur (Centaurus), the Wolf (Lupus), the Altar, the Southern Triangle, the Ship Argo (Argo Navis), the Flying Fish, Doradus, the Reticule, Eridanus (the River Po), the Phœnix, the Toucan, the Crane, the Indian, the Peacock, and the Southern Crown (Corona Australis).

The Southern Cross and the Ship Argo are magnificent groups indeed, and give to that region of the sky a splendor surpassed only by that of the huge hexagon at whose angles blaze Sirius, Rigel, Capella, Procyon, Aldebaran, and the Twins, with the ruddy glow of Betelgeuse marking the centre.

Zodiacal Constellations.—There are twelve Constellations lying along the great highway of the sun, in each of which he passes a month.

These are Aries (the Ram), Taurus (the Bull), Gemini (the Twins), Cancer (the Crab), Leo (the Lion), Virgo (the Virgin), Libra (the Balance), Scorpio (the Scorpion), Sagittarius (the Archer), Capricornus (the Goat), Aquarius (the Water-Bearer), and Pisces (the Fishes).

MYTHOLOGICAL HISTORY.

Cassiopeia.—Cassiopeia was the wife of Cepheus, the king of Ethiopia. She was of wondrous beauty. She boasted that her comeliness surpassed that of either Juno or the Nereides, or sea nymphs. This boast reaching the ears of the nymphs, filled them with resentment. These Nereides were great favorites with Neptune, the god of the sea. Neptune, to placate his favorite nymphs, sent a fearful sea-monster to ravage the country of Cassiopeia. Neptune refused to draw off the creature unless Andromeda, the lovely daughter of Cassiopeia, would be chained to a rock near the beach and exposed to the fury of the awful reptile. Perseus, returning from the conquest of the Gorgons, redeemed the beauteous maid by destroying the monster.

Andromeda.—Andromeda was the daughter of Cepheus and Cassiopeia. On account of the resentment of the sea nymphs, provoked by Cassiopeia's boast, Neptune sent a gigantic monster to ravage the whole of Ethiopia. An oracle being consulted, it was declared that nothing could appease the anger of Neptune but the sacrifice of Andromeda. She was, accordingly, chained to a rock on the Syrian coast. Perseus, arriving opportunely, through means of the Medusa's head which he was bearing home in triumph, turned the destroying monster into stone just as he was in the act of devouring the forlorn damsel. Perseus and Andromeda were married.

Perseus.—Perseus was one of the most charming characters of ancient fable. He was indeed an ideal hero. He was the son of Jupiter and Danæ. Soon after his birth the child and his mother were cast into the sea. They were borne a great way by the winds and currents, and finally rescued by some fishermen off one of the islands of the Cyclades, and entrusted by the king of the island to the care of the priests of Minerva's temple. Perseus, by the courage and nobility of his behavior, grew to be a great favorite with the gods. On a great feast-day of the king, his benefactor, Perseus promised to give him Medusa's head. The three Gorgons were Medusa, Stheno, and Euryale. Medusa was the only one of the sisters subject to death. Their bodies grew inseparably together, and were covered with impenetrable scales. These Gorgons had yellow wings and brazen hands, and their heads were wreathed round with numberless serpents. They were instantly turned to stone on whomsoever the eyes of the sisters were fixed. Pluto, the god of the Inferno, lent to Perseus a helmet having the virtue of rendering him invisible. Minerva, goddess of wisdom, gave him a polished buckler, and Mercury winged sandals. Conducted by Minerva, the hero came upon the sisters while they slept. He cut off Medusa's head with a single blow, and the immortal sisters, aroused by the noise, vainly pursued him, Pluto's helmet rendering him invisible. Perseus, Andromeda, and Cassiopeia were changed after death into Constellations.

Orion.—According to one account, Orion was the son of Neptune and a great huntress named Euryale. The hero took naturally to the chase, and became a hunter of high renown. Having vaingloriously boasted that he could slay any animal of the forest, a scorpion sprung up out of the earth and stung him to death, in punishment of his vanity. Diana placed him among the stars, directly facing the celestial scorpion. In stature and strength Orion was said to surpass all mankind. The giant was skilled in the working of iron, and walled in the coast of Sicily against the encroachments of the sea.

Gemini.—The Twins were the brothers Castor and Pollux, sons of Jupiter. They were among the heroes of golden-fleece fame, having joined the Argonautic expedition to Colchis, and performed prodigies of valor. Their supreme bravery is greatly extolled in fable; "one fought on foot, one curbed the fiery steed." In Grecian temples the brothers are represented riding side by side on white horses, armed with spears and their heads crowned with a glittering star. The Twins were looked upon as the friends of navigation, having driven all pirates from the Hellespont.

Canis Major.— The Great Dog very probably received its name from Egypt. The Nile was noticed to commence its periodic overflow just as Sirius, or the Dog-Star, of this Constellation rose in the east with the dawning of the day. Siris was the Egyptian name of the Nile, and hence Sirius, the great brilliant in Canis Major. Like a faithful dog, it gave warning of the approaching flood.

It is also very likely that Canis Minor was likewise an Egyptian invention. It precedes the rising of Canis Major, and is a faithful sentinel of its approach.

Ursa Major.—The Great Bear is understood to be Callisto, the daughter of a king of Arcadia. Jupiter became enthralled with Callisto's beauty, and Juno, in a fit of jealousy, changed her mortal rival into a bear. Jupiter placed Callisto among the Constellations.

Coma Berenices.—Berenice was the beautiful wife of Evergetes, one of Egypt's kings. She was fondly attached to her husband, and vowed to sacrifice her locks to Venus on the safe return of Evergetes from an expedition he had taken against the Assyrians. Evergetes having reached home unharmed, in fulfilment of her vow Berenice placed her shorn hair in the temple of the goddess of beauty. The locks were stolen from their place in the temple, and Conon, the king's astronomer, having discovered them in the sky, declared that Jupiter had placed them among the stars.

Boötes.—According to the Greeks, Boötes, also called Arcas, was the son of Jupiter and Callisto. Boötes became a hunter of great repute. Callisto, the hero's mother, was transformed by the jealous Juno into a bear. Boötes one day in the chase roused a bear, which was his own mother, but unknown to him. Just as he was about to slay her Jupiter snatched both up to the sky, where he placed them among the stars. Boötes is sometimes called Arctophylax, from the Greek of bear-keeper.

Corona Borealis.—According to the historian Plutarch, this crown of seven stars (only six in the asterism) was given by Bacchus to his spouse Ariadne, which after her death was placed among the Constellations. Ariadne, the daughter of the second king of Crete, was very unhappy in her first marriage to Theseus, a hero greatly celebrated in Grecian story. Theseus was confined by the king's orders in the famous labyrinth of Crete, to be devoured by the awful Minotaur (half-man and half-bull). Theseus slew the monster, and escaped from the labyrinth through means of a clue furnished by Ariadne. Theseus and Ariadne were married. Ariadne was, however, soon forsaken by the faithless hero. Her second marriage was a very happy one.

Lyra *(The Harp)*.—This is said to be the immortal harp of Orpheus, one of the Argonauts, and the father of song. It was given to him by Apollo. Orpheus played on this harp with so great a charm that his strains affected alike wild beasts, rivers, and mountains. The hero married Eurydice, one of the nymphs who used to listen to his songs. Eurydice, fleeing from the persecutions of an admirer, was bitten by a serpent and died of the venomous wound. Orpheus was inconsolable, and resolved to recover her at every hazard. With his celestial lyre he entered hell, and awakened such melody that even the furies relented. Pluto and Proserpine, the king and queen of the infernal regions, were moved to pity, and consented to let Eurydice go on condition that Orpheus would not look back while within the confines of their realm. The hero had almost reached the limits of Hades when he turned to catch a sight of the long-lost Eurydice. He saw her, but she immediately disappeared from his sight for ever. He was expelled from hell and denied all further admission. Orpheus was later put to death by Thracian women for misanthropy induced by his loss, his head cast into the Hebrus; and as it was borne down the current to the Ægean Sea, the constant lips still continued to utter the name of Eurydice.

MONTHLY ASPECT OF THE HEAVENS.

The earth makes a complete circuit of the heavens in twelve months. In one month it journeys eastwardly 30°, or the celestial vault turns every month apparently westward 30°.

Owing to this apparent westward motion of the heavens, the Stars and Constellations rise two hours earlier each successive month.

The Stars and Constellations that rise at midnight on January 1 will rise at 10 o'clock P.M. on February 1, and 8 o'clock P.M. on March 1.

The Stars rise two hours earlier every month, and in twelve months will gain twenty-four hours, or return to the place from whence we reckon.

The following are the positions of the principal Stars and Constellations on or about the first day of each month of the year:

January (8 P.M.)—In the East, the Manger just rising; Procyon (Canis Minor) near the horizon; the Twins higher up; Taurus (Aldebaran and the Pleiades) on the meridian. In the North, Cassiopeia and Perseus above the pole, and Ursa Major (Dipper) below and eastward. In the South-east, Orion. In the South-west, Fomalhaut (Piscis Australis). Perseus, Capella (Auriga), Andromeda, and Great Square near zenith. In the West, Job's Coffin (Delphinus), Altair (Eagle), and Vega (Lyra).

February (8 P.M.)—In the East, the Sickle and Regulus (Leo) just appearing. In the North, the Dipper lies east of the pole, and Cassiopeia west. The Twins are midway up the sky; Aldebaran (Taurus) overhead. In the South-east, Procyon (Canis Minor); Sirius (Canis Major); Orion. North of the Zodiac, Capella (Auriga) east of the meridian; Andromeda west of it. In the West, the Great Square of Pegasus sinking to the horizon.

March (8 P.M.)—In the East, Berenice's Hair just appearing. In the North, the Dipper still east, and Cassiopeia west, of the pole. On the Sun's path, the Sickle (Lion), Castor and Pollux (Twins), and Aldebaran (Taurus), west of the meridian. In the South-east, Procyon (Canis Minor) and Sirius (Canis Major). In the South, Orion. Capella (Auriga) in the zenith, and Andromeda west of the meridian. The Great Square just setting.

April (8 P.M.)—In the East, Arcturus (Boötes) rising. In the North, the Dipper above and east of the pole, and Cassiopeia correspondingly west. On the Zodiacal road, Spica (Virgo) just appearing, Regulus and the Sickle half-way up, the Bee-hive on the meridian, the great brilliants, Aldebaran (Taurus), Castor and Pollux (Gemini), going down in the west. In the North-east, Coma Berenices, Capella (Auriga), and Andromeda.

May (8 P.M.)—In the East, the splendid Vega (α Lyræ) just appearing. On the Zodiacal road, Spica (Virgo) midway up, Regulus and the Sickle (Leo) on the meridian, Castor and Pollux (Gemini), and Taurus (Aldebaran and the Pleiades) setting. In the North, the Dipper (Ursa Major) above the pole, and Cassiopeia below. In the South-east, the glowing fires of Sirius and Procyon; Orion sinking in the west. North of the sun's path and east of the meridian shine the Northern Crown, Arcturus, and Coma Berenices. In the North-west, the lustrous Capella.

June (8 P.M.)—In the East, the Swan and Eagle, with their first-magnitude gems, Alpha Cygni and Altair, are just appearing; Vega (Lyra) and the Polish Bull have already arisen. On the Zodiac, the red Antares (Scorpio) just appearing; Spica on the meridian; Regulus past; Taurus and Gemini toward the west. In the North, the Dipper above the pole, and Cassiopeia beneath. North of the Zodiacal highway, the Northern Crown and fiery Arcturus. In the North-west, Capella. In the South-west, Procyon going down.

July (8 P.M.)—In the East, Job's Coffin (Delphinus), Alpha of the Swan, and Vega. On the sun's path, Antares (Scorpio), Spica, and Sickle, with Regulus. The Northern Crown is almost in the zenith, and Arcturus west of it. In the North, the Dipper is west, and Cassiopeia east, of the pole.

August (8 P.M.)—In the East, Andromeda and Pegasus. In the North, Charles' Wain west of the pole, and Cassiopeia east. On the Zodiac, Antares (Scorpio) has passed the meridian, and Spica (Virgo) is sinking in the west. North of the Zodiacal road, Vega is just east of the meridian, and still further east are Job's Coffin and the Swan (Northern Cross). In the West, the Northern Crown and Arcturus (Boötes). In the North-west, Berenice's Hair.

September (8 P.M.)—In the East, Perseus, Andromeda, and Pegasus. In the North, the Plough (Ursa Major) below and to the west, and Cassiopeia above and east, of the pole. On the Zodiac, Antares (Scorpio) south-west; Spica (Virgo) sinking in the west. North of the Zodiacal road shines Vega (Lyra) on the meridian, to the east of which lie Job's Coffin, the Northern Cross (Swan), and Altair (Aquila); while west of the meridian is Taurus Poniatowskii (Polish Bull); and north of it, Corona, Arcturus, and Berenice's Hair.

October (8 P.M.)—In the East, Andromeda half-way up the sky. On the Zodiacal road, Antares (Scorpio) is far down in the south-west. In the North, the Dipper is below and west, and Cassiopeia above and east, of the pole. North of the sun's path, Altair (Eagle) and Alpha Cygni (Swan) are on the meridian; Job's Coffin (Delphinus) east of it; Vega is west of the meridian. In the

North-west, the Northern Crown and Arcturus; Berenice's Hair is sinking in the west.

November (8 P.M.)—In the East, Capella (Auriga) is just appearing. On the Zodiac, Aldebaran (Taurus) is just rising. North of the sun's path, Andromeda and Great Square east of the meridian; the Northern Cross (Swan), Job's Coffin (Dolphin), Altair (Aquila), and Vega (Lyra) west of the meridian. In the North, the Dipper is below, and Cassiopeia above, the pole. In the North-west, the Northern Crown.

December (8 P.M.)—In the East, the great Orion is just appearing. On the sun's path the Twins are just appearing; Aldebaran half-way up the heavens. In the North, the Great Bear is below, Cassiopeia above, and Perseus above and to the east of, the pole. In the North-east, Capella (Auriga). In the South, Fomalhaut (Piscis Australis) is west of the meridian. North of the Zodiacal highway, the Great Square is west of the meridian; and still further west sparkle the Northern Cross (Cygnus), Job's Coffin, the luminous Vega (Harp), and the white Altair (Eagle).

II.—THE STARS.

To the unassisted eye the radical distinction between a Star and a planet is, the apparent immobility of the one relatively to the rest of the heavens, and the wandering of the other.

Another difference is, that the Stars scintillate or sparkle more than the planets.

There appears to be no very clear explanation of this flickering of the Stars. It is, however, most probable that the cause is partially atmospheric, and partially due to the interference of light-rays coming from such vast distances.

When near the zenith the Star sparkles much less than when near the horizon, and the degree of scintillation is governed in a great measure by the character of the weather.

On certain nights none of the Stars seem to flicker, and on others again all the bright ones are noticed to scintillate strongly.

Among the planets, Mercury, Venus, and Mars have a perceptible sparkle; but Jupiter and Saturn scarcely ever flicker, and when they do it is of the feeblest character.

If the atmosphere occasions this tremulousness, ought it not to affect the planet equally with the Star? The planets have all a finite apparent size, while the Stars are the merest points. In the smallest telescopes the planets all have discs; in the most powerful optical instruments the Star is still a point.

This is offered as a reason for the greater sparkle of the Star. Also, the light of the planets is faint compared with that of the Stars, for the latter are glowing suns.

Again, on the summits of lofty mountains, where the atmosphere is much less restless than at lower altitudes, this tremulousness is very much diminished.

This scintillation of the Stars is usually accompanied with a flashing of prismatic colors.

Magnitudes.—The Stars have been divided into classes or magnitudes, according to their relative brightness. The lower the number that expresses a Star's magnitude, the brighter is the Star.

All Stars visible to the unaided eye are comprised in the first six magnitudes. Stars of the seventh and lower magnitudes are telescopic.

The telescopic Stars are divided down to the twentieth magnitude, and even lower.

Stars of the same magnitude are not of equal brightness; to class the Stars precisely according to their brightness would require a magnitude for every Star in the sky, as no two Stars are absolutely of the same lustre.

It is, too, a very difficult matter to define the limits of the magnitudes, or where one ends and the other begins. It is, therefore, understood that this division of the Stars is conventional and arbitrary.

Number of the Stars.—The number of Stars in both hemispheres visible to the unaided eye has been placed between five and six thousand. The number of Stars embraced in the different magnitudes increases rapidly as the lustre decreases.

There are about 20 Stars of the first magnitude, 65 of the second, 200 of the third, 500 of the fourth, 1,200 of the fifth, and 4,000 of the sixth.

Argelander, of Bonn, a great authority on Star cataloguing, has given a chart of 314,926 Stars of the northern sky between the first and tenth magnitude.

The British Association for the Advancement of Science gives a catalogue of 8,377 of the brightest Stars in both hemispheres.

The Stars visible to the telescope have been variously estimated from forty to one hundred millions.

Stellar Photometry.—There are many forms of the Photometer. A Photometer is an instrument for measuring the intensity of light. It may consist of a vertical screen of thin paper, a few inches from which is placed a cylindrical stick.

When two lights are to be compared, they are so placed behind the stick that each casts a separate shadow of the stick upon the paper screen. The lights are moved to or from the stick until their shadows on the screen appear equally obscure.

The squares of the distances of the lights from their shadows give the comparative intensities of the lights.

Instead of the stick a second screen parallel to the first is sometimes employed. This second screen, which is much thicker than the first, has an aperture cut in its centre.

When two lights apart from each other are placed behind the second screen they will cast separate illuminations through the aperture upon the first screen.

The experimenter changes the relative distances of the lights from the second screen until the illuminations on the first screen appear of equal lustre. The relative intensities will be as the squares of the distances of the lights from the first screen.

Alpha Centauri is computed to emit four, Vega about forty, Sirius seventy-two, and Arcturus two hundred times as much light as our own sun.

Professor Pickering has cultivated stellar photometry with such assiduity and success that it has assumed the rank of a separate branch of astronomic research. He has constructed a photometric catalogue of 4,260 stars, from ninety thousand observations of light-intensity.

According to the photometric measures of stellar brightness, it is estimated that the lustre of the Stars increases in geometrical progression, as the number of their magnitude decreases in arithmetical progression.

The Stars of one magnitude are reputed two and one-half times brighter than those of the magnitude next below it.

If the lustre of an average sixth-magnitude Star be taken as unity, that of the fifth-magnitude Stars will be $2\frac{1}{2}$; of the fourth, $6\frac{1}{4}$; of the third, $15\frac{5}{8}$; of the second, $39\frac{1}{16}$; and of the first about 98.

Sirius, however, is computed to be five hundred times as bright as an average sixth-magnitude Star.

It is also calculated that all the Stars of the first eight magnitudes give one hundred and forty-three times as much light as the well-known Vega in the Harp, and that all the Stars individually invisible to the unaided eye shed more light upon us than do all the visible or lucid Stars.

First Magnitude Stars.—

"O majestic Night!
Nature's great ancestor! Day's elder born,
And fated to survive the transient sun!
By mortals and immortals seen with awe!
A starry crown thy raven brow adorns,
An azure zone thy waist; clouds, in heaven's loom
Wrought, through varieties of shape and shade,
In ample folds of drapery divine,
Thy flowing mantle form; and heaven throughout
Voluminously pour thy pompous train."—*Young.*

The best authorities seem to rate the Stars of the first magnitude at twenty. Some limit the number to seventeen, and others to fifteen.

Sirius is the brightest Star in the sky, and shines in the constellation of the Great Dog. It is southeast of Orion, and not far from that great constellation.

The spectroscope demonstrates that the Stars shine by their own light, and are glowing suns.

Sirius is not only the brightest of Stars, but is a kingly sun. Sirius is about a million times as far from us as our own sun, and is calculated to exceed it more than a thousand times in volume, and about twenty times in mass.

Sirius is intensely white, with a delicate lilac tinge, and owes its brilliancy to incandescent hydrogen. Although, owing to its awful distance, Sirius appears to the unaided eye as fixed, still, according to the testimony of spectrum analysis, it is sweeping along through space at the rate of a thousand miles a minute.

Eta Argus is the second Star in the order of brightness. Its home is in the southern sky, being invisible in our latitude. It is a singular Star, and varies very much in brightness.

Canopus holds the third place among first-magnitude Stars. Being far down toward the south celestial pole, it is never visible north of the thirty-seventh degree of north latitude.

Canopus is immeasurably farther away than Sirius. Canopus is certainly a much grander sun than Sirius, and, as far as present appearances go, it is the king of suns. It is a brilliant white Star.

The next great brilliant is Alpha Centauri. It is a southern star, and invisible to us. It is the nearest of the fixed Stars whose distances have been computed, and is over two hundred thousand times more distant than the sun.

Arcturus comes next in order, and in northern latitudes is second only to Sirius. It can be easily discerned, its place being in the neighborhood of the well-known Northern Crown. Arcturus, when near the horizon, is of a deep red color, but when higher up is of a deep yellow.

Arcturus is beyond sixteen hundred thousand times more distant than the sun, and although it journeys through space at a rate of about fifty-four miles a second, still, owing to its enormous distance, it appears to travel only the eighth part of the moon's diameter in a century.

Capella, Vega, Procyon, Betelgeuse, and Rigel succeed Arcturus in the order named.

Betelgeuse (α Orionis) and Rigel (β Orionis) are the two bright Stars of Orion. The lower one, a sparkling white Star with a bluish tinge, is Rigel. Betelgeuse is a variable Star, of a rich deep orange hue.

Capella has a creamy or pearly lustre, and can be found by prolonging the line joining the two stars of the quadrilateral of the Great Bear nearest the pole.

Vega is a Star of brilliant whiteness, with a bluish tinge, and can be found at the corner of a triangle of which Arcturus and Polaris form the base. Vega owes its intense whiteness to glowing hydrogen.

Procyon is of a golden-yellow color, and, with Sirius and Betelgeuse, forms an equilateral triangle.

Achernar (α Eridani), Beta Centauri, Altair, Alpha Crucis, Aldebaran, Fomalhaut, Beta Crucis, Pollux, Antares, Regulus, and Spica follow Rigel in the order of their lustre.

Of these, Achernar, Beta Centauri, Alpha Crucis, and Beta Crucis belong to the southern sky, and are invisible to us.

Fomalhaut, though a southern Star, can be seen in our latitude low down toward the southern horizon. It is a beautiful Star with a slight reddish tint.

Aldebaran (Alpha Tauri) is of a rose-red color, and resembles the planet Mars. It is close to the well-known cluster of the Pleiades, or Hen-coop.

Antares (α Scorpii) is of a fire-red color. In summer evenings a line from the Pole Star through the edge of the Northern Crown will strike, near the southern horizon, this brilliant red Star.

When Vega is in the zenith, and Antares on the western horizon, Altair, a brilliant white star, will be found in a line midway between them.

A line drawn from the pointer nearest Polaris to the Star in the cup of the Dipper, diagonally across, and prolonged, will pass through Spica.

Spica is remarkable for its pure white light.

Pollux, of the Twins, is of a deep yellow color. It is the southernmost Star of Gemini, and, with Procyon and Betelgeuse, forms a right-angled triangle, Procyon being at the right angle.

Regulus is the beautiful white Star in the handle of the Sickle.

Stellar Distances.—To compute the distance to a fixed Star it is necessary to find its annual parallax. This annual parallax is the angle subtended by the radius of the earth's orbit at the Star's distance. It is the magnitude of the sun's mean distance as seen from the Star.

When it is considered that the motion of the earth around the sun brings us, at one time, a whole diameter of its orbit (one hundred and eighty-five millions of miles) nearer to a particular part of the heavens than we were six months before, we should expect a change in the relative distances of the Stars, as seen from the two points; that as we approached them they should seem to separate.

But owing to the awful distances of the Stars no such change, except in a few rare instances, is noticed to occur, even by the most delicate and powerful optical contrivances.

This journey of the earth from a point in its orbit to the opposite one gives an apparent oscillation of 6° to the planet Saturn on each side of its mean position.

The annual parallax of a Star, however, is only half its apparent displacement by a six months' journey of the earth. The distance of a body from the sun is almost inversely as the parallax.

If the annual parallax of a Star amounted to one second of an arc, the Star's distance would be about 206,000 times that of the sun.

Bessel, of Königsberg, published in March, 1840, the first parallax of a fixed Star. It was of the Star numbered 61 in the constellation of the Swan. Bessel made the parallax 0″.3483, corresponding to 600,000 radii of the earth's orbit.

Peters, of Pulkowa, confirmed the result in 1842.

Dr. Ball, of Dunsink, afterwards made the parallax 0″.47, and Professor Hall, of Washington, 0″.48.

Newcomb and Holden make the parallax 0″.51, corresponding to 400,000 radii of the orbit of the earth, and this is probably very near the truth.

Thomas Henderson found the parallax of Alpha Centauri to be almost one second of an arc, and Alpha is regarded as the nearest fixed Star.

Guillemin gives the following table of the eight most accurately measured Star distances, expressed in astronomical units, or radii of the earth's orbit:

	Radii of Earth's Orbit.		*Radii of Earth's Orbit.*
α Centauri, - -	211,330	ε Ursæ Majoris,	1,550,800
61 Cygni, - - -	550,920	Arcturus, - -	1,622,800
Vega, - - - -	1,330,700	Polaris, - - -	3,078,600
Sirius, - - - -	1,375,000	Capella, - - -	4,484,000

The astronomical units may be converted into miles by multiplying them by 92,500,000:

	Miles.
α Centauri,	19,548,025,000,000
61 Cygni,	50,960,100,000,000
Vega,	123,089,750,000,000
Sirius,	127,187,500,000,000
ε Ursæ Majoris,	143,449,000,000,000
Arcturus,	150,109,000,000,000
Polaris,	284,760,500,000,000
Capella,	404,770,000,000,000

Drs. Gill and Elkin have recently ascertained that the distance of Alpha Centauri is one-third greater than Henderson had computed it. They found, too, the parallax of Sirius to be double what it had been previously reputed, or reduced the Star's distance by one-half.

It is seen from the Star distances obtained that the brightest ones are not always the nearest to us.

Double Stars.—A great number of Stars, appearing to the unaided eye as single luminous points, when viewed through the telescope are seen to be double, or even multiple.

In some instances the proximity of the Stars to each other is attributable to the effect of perspective, the Stars lying in the same line of light, although they themselves are separated by an immeasurable distance.

In many other cases the Stars are about equally distant from us, are comparatively close together, are physically connected, and actually form pairs, or Star systems.

The physically double, however, are the only ones that ordinarily receive the name of double Stars.

Cassini, in 1678, first drew attention to the subject of double Stars.

Bode, in 1781, published a list of eighty double Stars.

Burnham, of the Lick Observatory, who is probably the best living authority on this subject, has published a catalogue of 1,025 new double Stars, to which he later added 42 new ones observed on Mount Hamilton.

These double and multiple Stars obey the laws of gravitation, and revolve about one another, or, rather, about a common centre, in regular periods, varying from 18 to 1,625 years.

The shortest computed period is that of 10.8 years, by Otto Struve, 1852, for the pair known as δ (Delta) Equulei, and the longest that of 1624.8 years, by Doberck, 1877, for ζ (Zeta) Aquarii.

The distance to 61 Cygni has been measured. This is a double Star, whose components are separated from one another by forty-five times the distance of the earth to the sun.

Yet their distance from us is so prodigious that the breadth of the great gulf that divides them is invisible to the unassisted eye, and we require the aid of a powerful telescope to part them.

Variable Stars.—Stars whose brightness undergoes periodic variations are called variables.

There are over two hundred known variable Stars, and a still larger number of suspected ones. Indeed, Mr. J. E. Gore gives a catalogue of seven hundred and thirty-six suspected variable Stars.

Probably the most famous of all the variables, on account of the great range of its fluctuations, is the Star marked in the catalogues as Omicron Ceti.

It was the first known periodical Star, its variability having been noticed by Fabricius, in 1596.

Hevelius calied it "Mira," or the Wonderful, which name it has since retained.

Its mean period is about 331½ days. It changes from the second to the tenth magnitude, or it is a sun that shines at one time a thousand times more brilliantly than at another.

During five months it is entirely invisible to the unaided eye; it then begins to appear again, increasing slowly in lustre for three months, until it shines as a star of the second magnitude. It holds this brilliancy for about two weeks and then begins to fade, and in three months again disappears.

Its periodicity is subject to irregularities, however, and the Star does not reach its greatest lustre after every period.

The cause of these changes of lustre in the variables is still unknown. Various working hypotheses are advanced to account for the phenomena, such as the revolution of a dark body around the luminous one; the rotation of the body itself, its sides differing in luminosity, or one side being completely dark, or spots of great dimensions, similar to sun-spots, floating over the surfaces.

It is thought that the fluctuations of Mira's light are jointly due to a dense absorbing atmosphere and great floating spots. Mira is regarded as a dying sun. It has a slightly reddish tint, and indeed the variables as a rule are of a ruddy hue.

Another noted variable is Algol, or Beta Persei. During two days and a half Algol, or the Demon, as the Arabs call it, is a Star of the second magnitude; it then begins to fade, and in about four and a half hours it sinks to the fourth magnitude. It remains, however, only a few minutes so faint as this, and begins then to again brighten, until in about four and a half hours more it regains its first lustre. All these changes in Algol are plainly visible to the unassisted eye.

The "eclipse" theory seems to fit the case of Algol better than that of any other variable. It is a white Star, and closely resembles Sirius. If its variability depended on an absorptive atmosphere, its individual rays would be attacked, or its color would vary with the change of lustre.

Algol is constant in respect to color, always remaining white. Again, the time of its obscuration is but the merest fraction of the whole period, and this would favor the satellite or eclipse theory.

Goodricke, in 1782, first proposed the hypothesis of a satellite revolving around Algol. It has held its ground since.

This hypothesis requires that the satellite be an enormous body, its diameter 0.764 times that of the Star, and its period of revolution around the primary two days, twenty hours, and forty-nine minutes.

Against this theory it must be urged that it is extremely hard to believe that an immense body is travelling around another, still more enormous, with only four thousand miles between their surfaces.

Another wonderful variable is Eta Argus of the southern skies. This singular Star varies from the sixth magnitude to a brilliancy exceeding that of Canopus, and approaching closely to the lustre of even Sirius. No law can be found governing its periodicity or its changes of brightness.

Temporary Stars.—Stars that suddenly appear, and after shining more or less brilliantly for a short period, either disappear altogether or remain as very faint objects, are called temporary or new Stars.

Tycho Brahé, in November, 1572, saw a very bright new star in Cassiopeia, which grew in lustre until it almost rivalled Venus, and after gradually fading during a period of seventeen months, finally disappeared from view.

We have records of above twenty of these temporary or new Stars.

On May 12, 1866, a new Star of the second magnitude appeared in the Northern Crown which certainly was not shining there four hours previously. It became invisible to the unaided eye nine days after its discovery, and it is now in the Star maps as a pale yellow Star of the tenth magnitude. Its sudden glow of lustre was due, according to the spectroscope, to incandescent hydrogen.

Dr. Schmidt discovered, on the 24th of November, 1876, a new Star of the third magnitude in the Swan, which is known under the name of Nova Cygni. Its spectrum was nearly similar in character to that of the new (*T*) Star in Corona.

It appears that Nova Cygni later changed into a planetary nebula. This extraordinary object now appears as a telescopic Star of the fourteenth magnitude.

What is the cause of the phenomena of temporary Stars? Rapid motion, electric and magnetic influences (Humboldt), the intervention of nebulous masses not self-luminous, and other improbable causes have been variously assigned.

The most plausible theory, however, seems to be that this sudden glow of light in temporary stars is due to the eruption of incandescent hydrogen from the interior.

Stellar Spectra.—Spectrum analysis enables us to affirm the presence or absence of certain substances in any light-source whatever, so that we can say from the spectroscopic observation of a Star's light whether or not it contains hydrogen, iron, copper, or other element.

Secchi, Huggins, and Miller were the principal founders of stellar spectroscopy.

Secchi was the first to make a spectroscopic survey of the heavens. He examined more than 4,000 Stars, which he classified, according to the character of their spectra, into four types.

The first type is called the Sirian, and embraces all the bluish-white Stars resembling Sirius and Regulus.

This spectrum is continuous, and crossed by four broad and intense dark bands, due to great quantities of hydrogen present in the stellar atmosphere. A number of very faint metallic lines are also perceptible in this spectrum.

The second type is called the Solar, and comprises all the yellow Stars resembling Aldebaran and our own sun. This spectrum bears a close analogy to that of the sun.

The third type comprises the bright red Stars resembling Betelgeuse and Antares. This spectrum is of the "fluted" kind, and has the appearance of a luminous colonnade, and is due to the absorption of light by the vapors of compound substances in the stellar atmospheres.

The fourth type is composed of telescopic red Stars. These Stars are of a very deep red and gleam like rubies; the peculiarity of the spectrum of this type appears to be due to the presence of carbon in their atmospheres.

The spectrum of this type appears fluted, and has three large bright spaces divided by darker ones. The spectra of all the Stars prove them to be suns, only differing from one another in the absorptive nature of their atmospheres.

The hotter a Star is, very probably, the simpler is its spectrum; it is not proven, however, though often asserted, that the white Stars are young suns, and the red ones expiring suns.

Their spectra give evidence that hydrogen, sodium, iron, and magnesium are present in almost all the Stars whose light has been analyzed; and the spectrum of Aldebaran, which has been most carefully studied, reveals the presence in that Star of hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury.

Colored Stars.—The twinkling of the Stars is usually accompanied with a flashing of different colors; but apart from the ever-changing tints occasioned by scintillation, they have real and permanent hues.

The greatest variety and contrast of color are found, however, among the double Stars.

We find combinations of green and red, orange and blue, yellow and purple, gold and lilac, white and blue, white and green, in Star pairs.

There are ash-colored, citron, fawn, mauve, puce, russet, and olive Stars. A decided green, blue, purple, or brown is never met in single Stars, and a cinnamon-colored Star is rare.

It seems to be the testimony of the spectroscope that the colors of the Stars are due to the nature of their vaporous envelopes.

Huggins, in 1864, laid down the principle that the colors of the Stars depend less on the intrinsic nature of their light than on the elimination by their atmospheres of certain light-rays.

Each Star really emits white light, but this light shines in one instance through bluish vapors, and comes out blue; and in another through orange vapors, and comes out tinged with orange.

The great majority of the lucid Stars are white or bluish-white; the yellow Stars come next in number, while only about two per cent. of the naked-eye Stars are ruddy.

Taurus and Orion are remarkable for their vast gatherings of white Stars, and Cetus and Pisces for their aggregations of yellow ones.

The estimations that have been made of Star colors are very unsatisfactory, owing to the wide difference between observers in this respect.

A very valuable catalogue of 650 red Stars was published by Birmingham in 1877, under the title of *Red Star Catalogue.*

Errors may arise, principally from three sources, in observing Star colors. These sources are the atmosphere, the telescope, and the eye itself.

Stars less than 20° above the horizon should never be observed for color, and haze and fog should be avoided.

The red appearance of the sun when low in the sky or enveloped in fog proves this.

The best telescope to employ in the observation of Star colors is a silvered-glass reflector.

If a refractor be used it should be of moderate aperture, as large lenses, however well corrected, are not perfectly achromatic, and throw a blue halo around the object. The silvered specula are practically free from this defect.

The eye-piece should also be as perfectly corrected for dispersion as possible, and the Star kept in the centre of the field of view, as the margin is never entirely achromatic.

Different eyes make different estimates of colors. We find great discrepancies among observers, shown in the tints assigned to Stars. Thus, it is well known that Struve was partial to red tints, and Secchi to yellow ones.

It frequently happens that persons with the greatest acuteness of vision have not a perfect color appreciation.

Owing to nervousness, strain, or illness, the same eye does not always form the same estimate of a color. The first good look at a Star is the best, as continued scrutiny distresses the eye, and a different hue is perhaps then assigned.

In examining Stars for color artificial light should be avoided by the observer as much as possible in order to form a proper estimate, as nearly all artificial light has a yellow tint, and biases the eye accordingly.

Stellar Motion.—To the unarmed eye the Stars appear to be relatively immovable. With the aid of very powerful and delicate optical instruments, however, a small apparent relative stellar displacement is discernible.

Thus, for instance, the Star 61 Cygni moves apparently one-third of the moon's diameter across the sky in a hundred years. In the same interval Alpha Centauri suffers an apparent displacement of one-fifth, and the brilliant Arcturus one-eighth, of the lunar diameter.

The distances of a few of the Stars have been measured. When the stellar distance and apparent velocity are known, the real stellar velocity is easily computed, Guillemin gives the following table of the velocities of seven Stars:

	Miles a Second.		Miles a Second.
Arcturus,	54	Alpha Centauri,	13
61 Cygni,	40	Vega,	13
Capella,	30	Polaris,	$1\frac{1}{2}$
Sirius,	14		

The spectroscope affords a method of computing the rate of velocity of the Stars in the line of sight, or in a direction to or from the earth.

In the solar and stellar spectra every element has its characteristic lines, and these lines, moreover, have their permanent places.

It has been noticed that the spectrum of a moving body shifts according to the direction of the motion. It is the spectrum as a whole that is driven hither or thither by the motion, the separate lines maintaining their relative distances.

It is proved by experiment that if the light-source is moving toward us, the spectrum will be shifted toward the violet end; and if away from us, it will be shifted toward the red end.

By measuring the spectral displacement the rate of velocity can be computed. After a great deal of care and industry, physicists have been able to make a scale showing the relation between the rate of velocity and the amount of displacement.

Professor Young was enabled, in 1876, to verify the correctness of the scale.

From the observations of the motion of spots on the sun, it is estimated that his eastern edge moves toward us with an equatorial velocity of a mile and a quarter a second, and his western edge recedes at the same rate.

The spectroscope, in the hands of Professor Young, showed almost the same speed for the sun's axial rotation.

Sirius, Betelgeuse, Rigel, and Regulus are retreating from us, and Arcturus, Pollux, Vega, and Deneb of the Swan are approaching us.

The rate of the sun's translation through space has been computed, and its direction indicated.

The computed rate of the sun's speed is four miles a second, and, with some very slight discrepancies, Argelander, Struve, Mädler, Airy, Dunkin, and others make the direction north toward Hercules, and away from Argus in the south.

A Star of the seventh magnitude, numbered 1,830 in Groombridge's catalogue, has the greatest proper motion of any in the heavens, its speed being estimated at two hundred miles a second.

Stellar Masses.—When the distance of a heavenly body and the apparent size of its disc are known quantities, its real dimensions or bulk can be easily determined.

The distances of some few of the Stars have been computed; but the most powerful telescope that has yet been made fails to give a single one of them an appreciable disc. So that no measure has ever yet been made of a Star's size. The mass or weight, however, of some few of the Stars has been calculated.

We know that there are numbers of double Stars, or of two stars revolving about one another and forming systems.

When the apparent distance apart of the Stars composing one of these doubles has been determined, and the real distance from us of the pair is known, the true distance in miles that separates them can be calculated.

And when we know their real distance apart in miles, and the periodic time of their revolution, their united mass, in terms of that of the sun, can easily be calculated.

The components of Alpha Centauri revolve about their common centre at a mean distance of $23\frac{1}{3}$ radii of the earth's orbit in a period of about $77\frac{1}{2}$ years. From this it is computed that their united mass is twice the sun's.

The Star 61 Cygni weighs about one-third of the sun.

Sirius and its companion circle about their common centre in about 49 years, and are sundered from each other by about 37 radii of the earth's orbit.

According to Kepler's third law (the squares of the times of revolution of the planetary bodies are proportioned to the cubes of their mean distances from the sun), a body situated 37 times more distant from the sun than our earth would have a periodic time of about 225 years.

The combined mass of Sirius and its companion is to the sun's as the square of 225 is to the square of 49, or as 21 to 1. Masses are inversely proportioned to the square of the periodic time.

III.—STAR-CLUSTERS AND NEBULÆ.

Star-Clusters.—We easily notice that the Stars are not uniformly spread out over the sky. Some portions of the celestial vault are much richer in stellar jewels than others.

Frequently quite a large number of Stars are seen gathered together within a small area. These bunches of Stars are called clusters.

It is very probable that the grouping together of these Stars is not due to chance, but that the individuals are physically connected and form great Star systems.

The unaided eye easily distinguishes many of the coarser clusters or groups, such as the Pleiades, the Hyades, Berenice's Hair, and Præsepe, or the Manger.

There are other clusters where the individual Stars cannot be discerned by the unarmed eye, and which appear without telescopic aid as Nebulæ, or whitish cloud patches.

Star-clusters are ordinarily of a rounded or globular form, although sometimes, too, they are of an irregular shape.

The clusters that look to the unaided eye as faint vaporous Stars may be easily resolved by a good telescope into individual Stars. There are numbers of clusters visible only in the telescope.

Nearly all Star-clusters appear in the telescope to have a remarkable condensation of light toward the centre. This is owing partly to perspective, and partly to a real condensation of the Stars, due to the influence of the central forces of the stellar system.

These little Stars composing the clusters, buried in space to such prodigious depths, and therefore appearing to us so pressed together, are in reality probably divided from each other as widely as our own sun is from its nearest neighbors among the Stars. In some of these minute clusters there are many thousands of Stars.

One of the most beautiful and striking of the clusters is in the constellation Hercules, and when seen with a great telescope is truly a glorious object, being considered by many observers unsurpassed, if, indeed, rivalled in splendor by any other telescopic sight in the northern sky.

The cluster is close to the Northern Crown, and in a line between the Crown and the brilliant Vega. The number of Stars in the cluster is reckoned at fourteen thousand.

A cluster of great beauty is the southern one in Toucan, and is visible to the unaided eye. Its centre is of an orange-red color, and its border white.

The clusters in the Centaur, Aquarius, and Perseus are visible to the unaided eye.

The greatest number of the Star-clusters is found along the Milky Way.

Nebulæ.—All the little whitish clouds, or luminous vaporous masses, scattered over various portions of the sky, go under the generic name of Nebulæ.

These objects are easily discerned from the clouds floating in our atmosphere by their relative immobility in space.

Some of the nebulæ are Star-clusters, which small telescopes can readily divide up into individual Stars.

Other nebulæ are partly resolvable, by a great telescope, into Star points, and partly not resolvable.

Another class of nebulæ absolutely defy resolution by the most powerful instruments.

Nebulæ of Regular Forms.—There are nebulæ of regular forms, such as the globular or spherical, the elliptical, the annular, and the spiral nebulæ.

Specimens of the annular nebulæ are found in the Harp, Swan, Scorpion, and Andromeda; and of the spiral nebulæ in the Hunting Dogs, Virgin, Lion, and Pegasus.

Nebulæ of Irregular Forms.—There are also the irregular nebulæ, of every conceivable form and entirely devoid of all symmetry.

Of the irregular class specimens are found in Sobieski's Shield, Taurus, Doradus, Orion, and Argus. These nebulæ have the most varied and fantastic shapes.

What appears as a regular nebula in a small telescope is not unfrequently resolved into an irregular one by a more powerful instrument.

Famous Nebulæ.—The most famous of all the nebulæ are the great ones in Andromeda and Orion.

The only nebula known before the invention of the telescope was that in Andromeda. It was recognized by the Persian astronomer Abdurrahman a thousand years ago.

The attention of observers was first, however, practically drawn to it by Simon Marius in 1612.

Huyghens may be said to have been the discoverer of the nebula in Orion in 1656, although it had been previously mentioned by Cysatus, in 1618, as a term of comparison with a comet.

There is a further division of nebulæ into the planetary nebulæ and nebulous Stars.

Planetary Nebulæ.—A planetary nebula is one whose disc is circular and of uniform lustre. These nebulæ have no condensation of light toward the centre, and resemble very much in appearance the discs of the outer planets seen in a telescope.

There is a planetary nebula in the Great Bear, and one in Andromeda.

Nebulous Stars.—A nebulous Star is a nebula of regular form, in the interior of which appears one or more Stars symmetrically placed.

If it be of the circular form, the Star is at the centre; if of the elliptical, two Stars are found situated at the curve's foci.

The Stars, in all cases, are quite distinct from the nebulæ.

There are double and multiple nebulæ forming systems. There are also variable nebulæ, whose light undergoes frequent changes.

A catalogue containing 6,251 nebulæ has been recently published.

The portions of the sky nearest the Milky Way are the poorest in nebulæ, while the regions around the poles of the great galactic belt have the greatest nebular wealth.

The constellation of the Virgin is richer in nebulæ than any other region of the sky.

Nebular Spectra.—The question as to whether all nebulæ could be resolved into stellar points were the optical instrument sufficiently powerful, has been answered satisfactorily by spectrum analysis.

The spectroscope has demonstrated that some of the nebulæ are not Star-clusters, but self-luminous, diffused vaporous matter.

On August 29, 1864, Dr. Huggins obtained the spectrum of the planetary nebula in the Dragon. This spectrum consisted of three lines, one fairly bright, and the others exceedingly faint.

It was the discontinuous spectrum of glowing gas, and radically differed from the stellar continuous spectra.

The bright line was due to nitrogen, and one of the faint ones to hydrogen; the substance of the third line is unknown.

The spectra of clusters are continuous, are crossed by dark lines similar to that of the sun, and show the light to be that of a solid or fluid body with a vaporous envelope.

The spectrum of the gaseous nebula, on the contrary, is that of glowing gas.

Dr. Huggins afterwards analyzed the light of as many as seventy nebulæ, and found that one-third of the number had the characteristic spectra of incandescent gas.

All the planetary, annular, and irregular nebulæ belong to the gaseous kind.

The great nebula in Andromeda, the spiral one in the Hunting Dogs, and, as a rule, all nebulæ reducible to clusters, give a continuous or stellar spectrum.

The Orion nebula has a discontinuous or gaseous spectrum.

Immobility of Nebulæ.—Some of the Stars are noticed to have slight apparent motions; the nebulæ, however, seem absolutely immovable.

The spectroscope shows most of the Stars that have been examined to have a motion in the line of sight, but no trace of displacement has ever been noticed in the nebulæ, even by this delicate test.

Not External Universes.—The old conceptions of Laplace and William Herschel about nebulæ being remote galaxies, or external universes, are now given up.

The analysis of the Magellanic Clouds, or the two great nebulæ near the Southern Pole, retired such notions entirely.

In the greater cloud, or Nubecula Major, as it is called, are found mixed together indiscriminately Stars, clusters, regular and irregular nebulæ, and nebulous streaks.

It cannot be maintained, then, that nebulæ are remote worlds of Stars, as some at least of them certainly lie within the limits of the sidereal system; and it is more than probable that the Stars and nebulæ are parts of a single scheme.

The Milky Way.—The Milky Way, or Galaxy, is the luminous zone or long nebulous train which stretches across the sky from horizon to horizon.

When completely traced this whitish band is found to extend, in the form of a great circle, around the whole celestial vault.

The outlines of this Star cloud are irregular and broken along its whole course, and its glimmer very variable.

The zone of cloudy light divides into two branches, one faint and interrupted, and the other comparatively bright and continuous. The branches, after remaining apart for a distance of 150°, again unite.

The brightest part of the Milky Way in the northern hemisphere traverses the Eagle and the Swan; but the brightest portion of the whole galactic highway runs through the southern asterisms of Argus and the Altar.

Where the Galaxy enters the Southern Cross, and where its breadth is narrowest, is seen the famous pear-shaped opening called by mariners the Coal Sack.

The breadth of the Milky Way is four times greater in some places than in others.

The Galactic Circle cuts the equinoctial or celestial equator at an angle of 63°, and at points close to the great Orion and Ophiuchus.

The Milky Way owes its light to irradiation, or the united lustre of vast numbers of very faint Stars.

The Milky Way can be resolved with a good telescope almost entirely into Stars. William Herschel estimated the number of Stars in the Galaxy at eighteen millions.

The poles of the Galactic Circle are in Berenice's

Hair and the Whale. It is estimated that the Stars are thirty times more numerous in the Galactic Circle than around its poles.

Structure of the Universe.—The great Milky Way, embracing the sun and all the Stars we see, is the visible or stellar universe.

All observers agree that our sun is a member of this sidereal system, and we can never, consequently, have a proper idea of its true appearance. To form an absolutely true conception of the structure of this system of Stars we should be able to view it from the outside.

Thomas Wright, of Durham, formed the first definite notion of its construction, and is the father of the "Grindstone Theory," or that the stellar system has the shape of a flattened millstone.

Kant came next with his theory of "Island Universes." He regarded the nebulæ as external universes, equal in size to the Milky Way. His hypothesis was taken from his imagination, and has no scientific value.

William Herschel, after the noble work of surveying the whole heavens with his great telescopes, proposed the "cloven flat disc" hypothesis, or that the structure of the visible universe is that of a flat disc, of irregular shape, with one of its halves cleft from the rim to the centre, and its breadth very much greater than its thickness. He placed our sun at almost the centre of the disc.

He estimated the thickness of this flat disc to be eighty times greater than the distance of the Stars of the first magnitude, and its breadth twenty-three hundred times greater.

As the foundation of his theory, Herschel assumed the Stars to be uniformly distributed in space.

He afterwards gave up this assumption, and so abandoned his hypothesis.

He later invented another method of determining the arrangement of the visible Star system, based, however, on the assumption that the brightness of a Star affords an approximate measure of its distance. This assumption must be abandoned, although Herschel maintained it to the end.

The most powerful telescopes have never been able to discern the smallest disc in a fixed Star. We are, therefore, totally ignorant of their real size. We cannot then say whether the greater lustre of a Star arises from its greater nearness, greater size, or the greater intensity of its light.

The theories on the construction of the sidereal universe ventured up to the present are of little moment, so much has to be assumed.

The Magellanic Clouds.—The Magellanic Clouds are two large nebulous spots near the Southern Pole, and distinctly visible to the unassisted eye.

They are situated in a region of the sky remarkably destitute of Stars, and are consequently very picturesque objects, being considered one of the wonders of the heavens.

The larger and brighter cloud lies between the Pole and Canopus, the smaller and fainter one between the Pole and Achernar.

The rays of the full moon render the lesser cloud invisible.

The larger of the clouds is also called Nubecula Major, and the smaller Nubecula Minor.

The great cloud covers a space of the sky of forty-two, and the lesser of ten, square degrees.

These clouds are not a part of the Milky Way, with which they are not connected, nor indeed with one another.

Sir John Herschel resolved the clouds with his twenty-foot reflector as follows: The Nubecula Major into 582 Stars, 291 nebulæ, and 46 clusters; and the Nubecula Minor into 200 stars, 37 nebulæ, and 7 clusters.

In no other part of the sky are so many stellar and nebulous masses thronged together in an equally small area as in the Nubecula Major.

The first notice of these clouds is found in the writings of a Persian astronomer of the tenth century, Abdurrahman Sufi, of Irak, who refers to the larger cloud as the White Ox.

They received the name of Cape Clouds from the Portuguese, and the more familiar one, by which they are ordinarily known, from the first circumnavigator of the globe, the famous Magellan.

CHAPTER XIII.

CELESTIAL PHOTOGRAPHY.

The Principle of Photography.—In the sunbeams there are heating, luminous, and chemically-active rays. These chemical or actinic rays possess the property of blackening the salts of silver, and particularly the iodides and bromides.

This property of light, which is the life of the photographer's art, was known to the alchemists of the twelfth century. They had a preparation known as Luna Cornea, or Horn Silver (chloride of silver), of snowy whiteness, which was observed to blacken by exposure to sunlight.

Priestley and Scheele guided the infant steps, and Wedgwood, Davy, Niepce, Daguerre, and Talbot aided the growth of actinism.

But the greatest name in photography is probably that of F. Scott Archer, who, in 1851, introduced the collodion process into the art.

The Collodion Process.—A peculiarity of both ether and alcohol is that they evaporate rapidly when exposed to the air.

Collodion is dissolved in a mixture of ether, alcohol, and cadmium iodide, or other soluble iodide. A glass plate is coated with this solution and exposed to the air. The ether and alcohol quickly evaporate, and a slender film of the collodion and iodide adheres to the glass.

The glass is then immersed in a bath of nitrate of silver, saturated with silver iodide; and the iodide of the film becomes iodide of silver, the cadmium being replaced by the silver.

By the exposure of the plate thus prepared to the sunbeams passing through the lens of a camera obscura, an invisible image of the surface reflecting the light rays is formed.

The plate is then treated with a solution of pyrogallic acid, or of proto-sulphate of iron, mixed with a small quantity of acetic acid, and the image appears as a negative, in which the lights and shadows answer respectively to the shadows and lights of the original.

The image is fixed by pouring upon it a solution of cyanide of potassium, or steeping the plate in hyposulphite of soda.

When the collodion film is exposed in the camera while still moist with the nitrate of silver solution it is called the wet collodion process, and is very sensitive to light rays.

When the free nitrate of silver is washed off from the plate, and the film allowed to dry in the absence of light, it is called the dry collodion process, and is much less sensitive to the tithonic rays than the wet plate.

First Steps.—Dr. Henry Draper, of New York, and Professor Bond, of Cambridge, made the first experiments in Celestial Photography. Warren De la Rue, however, reached the first valuable results.

In 1853 he took some good pictures of the moon by the collodion process, using a reflector of thirteen inches.

In 1857 he obtained, by an almost instantaneous exposure, the first Solar Photograph of real value ever taken.

The first really successful photograph of a solar eclipse was taken by him on July 18, 1860.

Tebbutt's comet (comet 1881, III.) was the first one satisfactorily photographed. The actinic strength of cometary rays is exceedingly small. An exposure of about three days would be required to get a good impression of a comet by the wet collodion process.

A new process had, however, been recently invented, by which the wet collodion plates were replaced by dry "gelatino-bromide" ones of extraordinary sensitiveness.

In these plates silver bromide is exclusively used as the sensitive substance, and has a reducing power of its own.

Janssen, by this new process and the aid of a reflector of great light-gathering power, obtained a photograph of this comet with half an hour's exposure.

Dr. Draper also obtained a good photograph of this comet.

Bond and Rutherfurd were the pioneers of Stellar Photography.

Advances.—A fair photograph of the great nebula in Orion was taken by Draper in 1880, and Ainslie Common obtained a magnificent picture of this wonderful object, in 1883, from an exposure of thirty-seven minutes, with the assistance of a silvered-glass reflector of thirty-six inches.

This is a miracle of the photographer's art. The most skilful artist could not by years of industry take as true a hand sketch of this nebula.

Dr. Huggins first applied this dry-plate process of wonderful sensitiveness to celestial objects in 1876. A perfect picture can be obtained by this method from an exposure of the one-hundredth part of a second.

Indeed, there is no limit to the briefness of time in which a good picture can be taken by this almost infinitely sensitive plate, if the light be sufficiently strong. And objects whose light-beams are of almost infinite feebleness can be photographed by continued exposure.

A very faint object appears no brighter to the eye at the end of an hour than at the end of the first second. But the contrary is true of a photographer's plate. The effect accumulates almost indefinitely.

This property of the plate is of priceless value to the astronomer. The plate that can be made sensitive enough to take a perfect impression of a bright object in the hundredth part of a second will take equally as good an impression of an object one hundred times as faint from an exposure of one second, and of another one thousand times as faint in ten seconds.

By means of long exposures of sensitive plates photographs have been obtained of stars and nebulæ absolutely invisible in the most powerful telescopes, and an hour's exposure of one of these plates will give a fuller and a more accurate star-chart than an observer's work of many years by the old methods. Celestial Photography is indeed advancing with rapid strides.

CHAPTER XIV.

CELESTIAL LAWS.

Laws of Motion.—The three laws governing Motion were, in the main, discovered by Galileo and Huyghens, although Newton first presented them in a systematized way in his *Principia.*

That a body will continue in the state in which it is, either of rest or of uniform rectilinear motion, unless acted on by some force to change its condition, is the first law of Motion or the principle of inertia.

The second law of Motion is, that change in the direction of motion is always proportioned to the force applied, and will take place in a right line with the impressed force.

The third law of Motion is, that action and reaction are equal, and in opposite directions; or, the mutual actions of any two bodies are always equal, and oppositely directed in the same straight line.

These three great laws prevail throughout the universe of matter, and have been established by experiment, aided by calculation.

Laws of Gravity.—The intensity of the attraction of gravitation is in no way controlled by the nature of the substances drawing one another, but depends altogether on the magnitude of their masses.

This force differs entirely from magnetic attraction, and is incomparably less intense, being only infinitesimal where small masses are concerned.

It is computed that two solid cast-iron balls, about fifty-three yards in diameter, and one mile apart, will attract one another, owing to gravitation, by a force equal to about one pound pressure.

No screen nor intervening object intercepts the attraction of gravitation.

Galileo discovered, by experiment and observation, the laws of terrestrial gravitation, and since his time it has been known that this force is inherent in the earth.

The laws of terrestrial gravitation, as illustrated in falling bodies, may be concisely stated as follows: First, all bodies near the earth's surface fall in straight lines towards the earth's centre, or in lines perpendicular to the surface of still water.

Secondly, all bodies, whatever their quantity of matter, must fall to the earth from the same height with equal velocities.

Thirdly, bodies falling towards the earth under the influence of gravity have their motion constantly accelerated.

Fourthly, the force of gravity is proportioned to the quantity of matter attracting.

Fifthly, the force of gravity varies inversely as the square of the distance from the centre of the earth; or, the attraction of gravitation is inversely as the square of the distance.

Kepler's Laws.—John Kepler, of Würtemberg, after many years of assiduous observation, discovered the three great laws governing the motion of the planetary bodies around the sun.

Kepler was a man of extraordinary perseverance, and although he repeatedly failed to make his theories agree with observation, still his profound conviction that God had established fixed laws to govern His world animated him to constantly fresh endeavors to discover these laws, until he achieved one of the most glorious triumphs in the history of Astronomy.

Kepler first chose a circle for the hypothetical path of the planets, but soon discovered that he could not reconcile observation with a circular path, and so abandoned that form of curve.

He next tried the ellipse, and found, on this hypothesis, that the theoretic and observed places of the planets closely agreed.

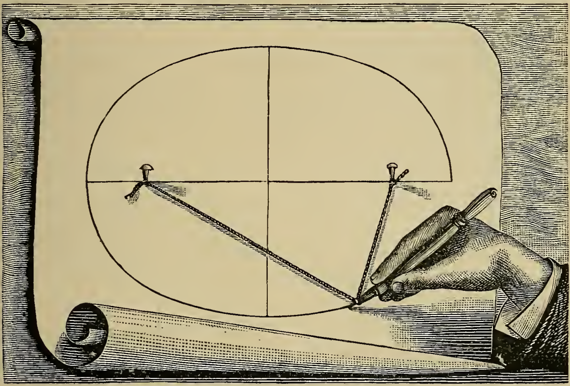

Fig. 12.—Describing an Ellipse.

The Ellipse.—An Ellipse is a conic section formed by cutting a right cone with a plane oblique to its sides. The characteristic feature of the curve is, that the sum of the distances of any point in it from two fixed points within is constant. The two fixed points are called the foci.

A simple way of describing an ellipse is to fasten on a plane surface the two ends of a thread with pins, and make a pencil move on the plane, keeping the thread constantly stretched.

The thread must be longer than the distance between the pins.

The pins will be found at the foci. The axis of the curve running through the foci is called the Major Axis, and is equal to the length of the thread.

The Eccentricity.—The eccentricity of an ellipse is the distance of its centre from either focus, and the less it is the closer does the ellipse approach the circular form.

The Radii Vectores.—The lines joining the foci with any point in the curve are called the Radii Vectores.

The first law of the planetary motions is that the orbits of the planets are ellipses, having the sun at one of their foci.

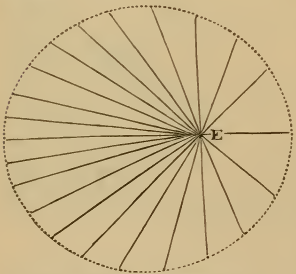

Fig. 13.—Radii Vectores.

That a line joining the centres of the sun and a planet sweeps over equal areas in equal times, is Kepler's second law.

Although the planet when in the part of its orbit nearest the sun moves more rapidly and passes over a greater arc in the same interval of time than when it is farthest away, still the triangular space travelled over by the radius vector is always the same for equal times.

Third Law.—The squares of the periodic times of the revolutions of the planets are proportioned to the cubes of their mean distances from the sun.

Universal Gravitation—Newton generalized the laws of Gravitation by showing that they extended to the moon, the planets, and the sun.

Newton knew that if the force of gravity reached from the earth to distant bodies, it should decrease as the square of the distance from the earth's centre increased.

The moon is about sixty times as far as the earth's surface from the earth's centre, and the force of attraction at the moon ought to be sixty squared times weaker than it is at the earth's surface.

Newton made the computation, and found that the moon falls the one-twentieth of an inch from a tangent every second toward the earth, and thus demonstrated that our satellite obeys the law of gravitation.

Newton's law is that every body of matter in the universe attracts every other in direct proportion to its mass, and in the inverse ratio to the square of the distance.

The observations of the conduct of double stars show that this great law is also paramount in the stellar systems.

Planetary Perturbations.—The first law of Kepler concerning the ellipticity of the paths of the planets around the sun is only rigorously true when the planets are regarded as immaterial points, and the sun truly spherical or homogeneous.

But the planets being really great massive bodies acting and reacting upon one another and upon the sun, the shapes and positions of their orbits undergo continual though small changes, called Perturbations.

These perturbations are of two kinds, periodic and secular.

Periodic Perturbations.—The perturbations or variations produced in a planet's orbit by the disturbance of the other planetary bodies during its periodic time, or in the course of a single revolution, are known as periodic perturbations.

Secular Perturbations.—The periodic perturbations continually occurring form a series or cycle of changes, requiring great periods of time for their completion, and so are called secular perturbations or variations.

Laplace and Lagrange have demonstrated that these perturbations do not endanger the stability of the planetary system, but are compensated by the return of the planetary orbits, after great lapses of time, to their former shape and position.

Precession of the Equinoxes.—The Ecliptic, or sun's apparent path, crosses the earth's equator, to which it is oblique, in two points, called the Equinoctial Points from the fact that the nights and days are equal all the world over when the sun is in these parts of his path.

There is a great bulge, or protuberance, around the equator which the sun constantly attracts towards itself, or towards its own apparent path rather, the Ecliptic.

The consequence of this attraction is a slight motion of the earth's equator toward the Ecliptic, or a forward movement of the equinoctial points along the Ecliptic. This is really a precession, or a moving forward, of the equinoxes.

This motion of the earth's equator imparts a motion to the earth's axis, or an apparent motion to the celestial pole. Owing to precession, the celestial pole will make a complete revolution in 25,868 years.

Nutation.—The moon also attracts this same equatorial bulge, and gives it another and more rapid motion, by which the celestial pole makes an apparent revolution in 18.6 years.

This motion or nodding of the earth's axis is called Nutation.

The moon's path crosses the earth's at two points, called the moon's nodes, and Nutation is equivalent to a precession of the moon's nodal points along the Ecliptic.

Lunar Perturbations.—The sun's attraction on the moon causes variations in the lunar orbit.

At new moon the moon is nearer to the sun than the earth is, and the moon is more attracted toward the sun than is the earth. At full moon the earth is nearer to the sun than the moon is, and the earth is more attracted than the moon. In both these cases the tendency of solar attraction is to separate the earth and moon.

At the quarters the earth and moon are about equally attracted, but the direction of the attraction is not the same for both, and the effect of solar gravitation is to draw the earth and moon nearer to one another.

Evection.—The earth, the moon, and the sun are in a line at full and new moon. This line is called the line of the Syzygies.

When the moon is in the first and third quarters it is said to be at the quadratures.

Consequently, the solar influence tends to increase the gravity of the moon to the earth at the quadratures, and to diminish it at the syzygies.

When the moon is in that part of its orbit nearest to the earth, it is said to be in Perigee, and farthest from the earth, in Apogee.

The line joining the perigee and apogee is called the line of the Apsides.

The eccentricity of an elliptical orbit is the distance from the centre to either focus.

The sun's attraction causes the moon's orbit to be most eccentric when the line of the apsides is in the syzygies, and least when the line of the apsides is in the quadratures.

The perturbation of the moon's orbit, owing to this change of its eccentricity caused by solar attraction, is called the moon's Evection.

Motion of the Apsides.—Another of the lunar perturbations is, that the line of the apsides, owing to planetary disturbance, makes a complete revolution in 8.8 years.

This motion of the line of the apsides (the line joining the perihelion and aphelion points in planetary orbits) is common to all the planetary bodies, but is much less remarkable in their case than in that of the moon.

The Tides.—Twice a day, at intervals of about twelve hours and twenty-five minutes, the sea-coasts present the well-known spectacle of the flow of the tide.

The tide by degrees rises, gaining on the beach, which it covers to a greater and greater height; and after six hours' swelling attains its maximum.

Scarcely is the moment of high-water or flood-tide attained than the flow of the water ceases, the descent begins, and the ebb succeeds to the flow.

Between two consecutive flood-tides there is an interval of about twelve hours and twenty-five minutes.

Thus, from one day to another high water is about fifty minutes behind.

The transit of the moon over the meridian is also about fifty minutes later each successive day.

High water reaches the meridian fifty minutes later each successive day, and each successive day the moon crosses the meridian fifty minutes later.

Nothing seems clearer than that high water and the moon travel along together. In twenty-nine and a half days, or the periodic time of a full revolution of its orbit by the moon, the tide is twenty-four hours late, and our satellite is also twenty-four hours behind, having in that interval made a complete circuit of the heavens.

The moon, by the force of her gravity, draws the waters of the earth into an oval form towards herself.

The earth daily rotating on its axis brings some portions of its liquid mass nearer to the moon than other portions. The bodies of water nearer to the moon will be more strongly attracted by her than those more remote.

The sun attracts the terrestrial waters similarly as the moon.

The tides are caused by the unequal attractions of the sun and moon upon the waters of different parts of the earth.

The moon, owing to her greater proximity, produces a greater tide than the sun, not, however, because her actual amount of attraction is thereby rendered greater than the sun's, but because her attraction for the different parts of the earth is very unequal, while that of the sun is nearly uniform.

It is the inequality of gravitation, and not its real amount, that produces the tides.

The sun is distant from the earth about 92,500,000 miles, and the earth's diameter is only about the one twelve-thousandth part of this distance, so that the solar attraction will be nearly the same on all parts of the earth.

But the earth's diameter is one-thirtieth of the moon's distance; and the moon acts, consequently, with considerably greater power on one part of the earth than on another.

It is computed that the tide-producing force of the sun and moon is equal to their mass divided by the cube of their distances.

The sun is four hundred times more distant than the moon, and by an easy calculation it is found that the tide-producing force of the moon to that of the sun is as 5 to 2.

At new and full moon the sun and moon act together on the waters, and produce the spring-tides, or "the tides of the syzygies."

At the first and last quarter of the moon the sun and moon act in opposition on the waters and produce the neap-tides, or "the tides of the quadratures."

The variations of the moon's distance from the earth influence the tides considerably. The tides are greater when the moon is in perigee than in apogee, and should the moon be in perigee during the syzygies the tides would be unusually high.

The variation in the sun's distance does not materially affect the tides.

Another cause of change in the magnitude of the tides is the amount of the declinations (distance from celestial equator) of the sun and moon.

The nearer these bodies are to the equator the higher proportionately will be the tides at the equator.

The equinoctial spring-tides occur when the moon is near the equator, on March 21 and September 22.

When the earth is attracted by the sun or moon, it is attracted altogether, and the force acts on its centre.

The particles of water just under the moon are nearer to the moon than is the earth's centre, and these particles are more strongly drawn toward the moon than is the earth's centre, and consequently rise up, producing a tide.

The particles of water on the side of the earth away from the moon are less attracted than the earth's centre, so that the earth is drawn away from the water, causing the water to rise on the land, producing a tide on the side of the earth opposite to the moon.

Thus there are two tides at the same time, one on the side of the earth nearest the moon, and one on the side farthest away. On one side the water is pulled away from the earth, and on the other the earth is pulled away from the water.

The tidal wave is an undulation, and not a progressive motion, unless where the water is very shallow.

The tidal wave does not reach the meridian simultaneously with the crossing of the moon, because the water is retarded by its inertia, and the friction of the bottom and the banks of the seas.

The wind, the depth and extent of seas, the direction and configuration of coasts, influence the tides.

Inland seas and great lakes have no perceptible tides, because their extent, though considerable in itself, is exceedingly small compared with the whole earth.

New York has a tide of about five feet; Boston, eleven; Apple River, fifty, and Fundy Bay, in New Caledonia, nearly one hundred feet.

It is thought that the tides act as a friction-brake upon the earth's rotatory speed, lengthening the day.

On this hypothesis it is computed that, after the lapse of sufficient time, the day will grow to be as long as the month, and after a still much greater period will equal the year, our planet ultimately turning the same face always toward the sun.

It is said that the lunar tides have acted similarly, but much more strongly, and so more rapidly, on the moon's rotatory velocity, until the lunar day now equals the month, and our satellite keeps the same face constantly toward its primary.

CHAPTER XV.

CELESTIAL MEASUREMENTS.

Elements.—The precise position of a place upon the earth's surface is known by its Latitude and Longitude.

The Latitude is the distance north or south of the equator, measured on the meridian of the place.

Longitude is measured along the equator, and is the portion of that great circle intercepted between the meridian of a place and some assumed meridian.

The elements determining the place of an object in the heavens are Right Ascension and Declination.

Declination.—Declination is the celestial element corresponding to terrestrial latitude, and is the distance of a heavenly body north or south of the Equinoctial.

The Equinoctial is a great circle of the heavens, being the projection of the earth's equator upon the celestial sphere.

Right Ascension—Right Ascension corresponds to our longitude, and is measured along the Equinoctial eastwardly from the point of its March intersection with the Ecliptic, or sun's apparent path.

The Ecliptic is inclined to the Equinoctial at an angle of 23° 28′, and intersects the latter in two points, called the Equinoxes.

Right Ascension is reckoned from the Vernal or March Equinox, or first point of Aries, and is measured eastwardly through 360°.

Right Ascension is never reckoned westwardly.

Frequently the element employed instead of Declination is the Polar Distance.

Polar Distance.—The Polar Distance is measured from the Celestial Pole along a great circle vertical to the Equinoctial.

The Polar Distance is the complement of the Declination (90° — Declination), and is indeed the same element.

Distance of an Inaccessible Object.—In computing the distances of the heavenly bodies it is necessary to invoke the aid of trigonometry to some slight extent.

One of the very first steps in trigonometry is to determine the distance of an inaccessible object, having the length of a base line, and the angles at the extremities of this base line subtended by the object and the line.

Three parts of a triangle being given, the triangle can be easily solved, and the other elements found.

The solution is still simpler if the triangle be a right-angled one.

In finding the distances of celestial bodies the triangle usually employed is a right-angled one, as the horizontal parallax is mostly used.

In solving a right-angled triangle it is sufficient to know the base and the angle it subtends.

To find the distance of a heavenly body it is enough, then, to have a measured base line, and the angle subtended at the body by this base line; or, in reality, the magnitude of the base line as seen from the distant body.

Parallax—This angle, or magnitude, is called the parallax of the body, and is really its apparent displacement when viewed from both ends of the base line.

For instance, if the moon, when near to a fixed star, be viewed at the same instant by two observers four thousand miles apart, one of them will see it nearer to the star than the other. The reason of this is, the moon, being comparatively close to the observers, will suffer an apparent displacement by being viewed from two positions so widely separated; while the fixed star will suffer no apparent displacement, owing to its almost infinite distance.

This apparent displacement of the moon is its

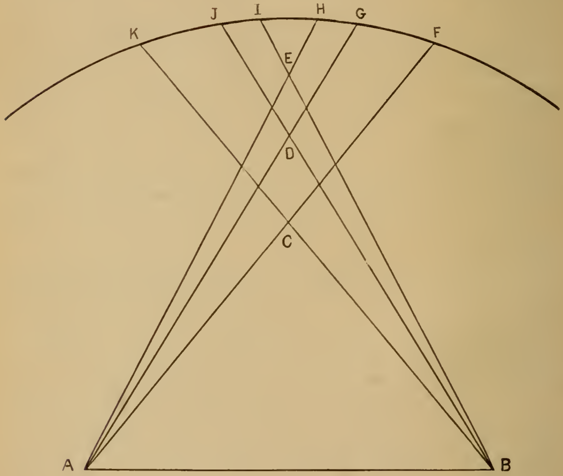

Figure 14.

parallax for a base line of four thousand miles, or is the magnitude of four thousand miles as seen from the moon, and is considerable.

The fixed star suffers no displacement, because four thousand miles seen from a fixed star is the merest point and has no magnitude whatever.

The nearer a body is the greater is its parallax; and the more distant, the less the parallax.

When A and B (Fig. 14), a thousand miles apart, observe at the same moment a heavenly body, C, it will appear to A thrown back on the sky at F, and to B at K. The parallax, or apparent displacement of C, viewed from A and B, is the arc, K F, or angle, A C B.

When the object is more distant its apparent displacement is less, as represented by the angle, A D B, or arc, J G.

When the heavenly body reaches E its parallax is still less, and is measured by A E B or I H.

Parallax, in general, then, is the apparent displacement of an object as seen from different positions.

Diurnal or Geocentric Parallax.—The daily or geocentric parallax of a body is the apparent displacement it suffers when seen from the surface and from the centre of the earth.

When the heavenly body, B (Fig. 15), is in the zenith of the observer, A, it will have no daily or geocentric parallax, as it will appear at D both to A and C.

When the observer, A, views the body, E, it will appear on the sky at F; but when seen from the centre of the earth it will appear at G. The arc G F is the apparent displacement of the body, E, as seen from A and C, or is its daily or diurnal parallax.

Horizontal Parallax.—The horizontal parallax of a heavenly body is its apparent displacement caused by the whole radius of the earth, and is its greatest geocentric parallax.

Thus A, in the figure, will see the body, H, in his horizon at I; but from C it will appear at K, and its horizontal parallax is I K, or the angle C H A, being the magnitude of the earth's radius as seen from H.

Diurnal Method of Parallaxes.—Finding the parallax by means of the daily revolution of the earth is called the "Diurnal Method of Parallaxes," and is the one now commonly employed.

The moon's position relatively to a fixed star is noticed, and after the earth passes through a space of six hours, is again noticed.

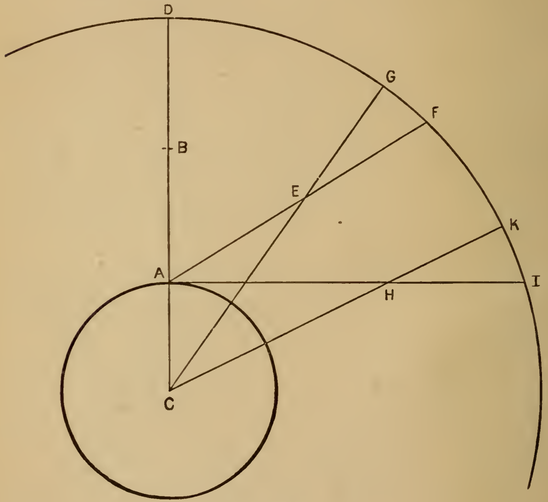

FIGURE 15.

The difference of these distances from the fixed star, allowance being made for the moon's own motion and refraction, will give the moon's horizontal parallax.

The moon's horizontal parallax being known, to find its distance is, as already mentioned, solely the solution of a right-angled triangle, the base and opposite angle being given.

This method of finding the distances of the heavenly bodies by the geocentric parallax is confined to the Moon, Mars, and the Minor Planets.

For further distances the earth's radius has no practically appreciable parallax.

Finding the Sun's Distance.—The horizontal parallax of the sun is so extremely small that it cannot be obtained directly with any accuracy, owing to the great refraction or bending of the light-rays near the horizon.

Many indirect methods have been resorted to by observers, however, to determine it.

The orbits of the planets are so connected by Kepler's laws that if the interval dividing any two of them can be accurately ascertained, the sun's distance can easily be deduced.

One of the indirect methods of finding the sun's parallax is by the observation of the transit of Venus across the sun's disc.

When two observers on different parts of the earth view the transit of the planet, they will see Venus thrown against the face of the sun as a black spot, but not in the same place.

The planet will not appear to enter on the sun's disc at the same absolute moment at the two stations, and therefore the paths, or chords, traversed will be different.

The chords will be of unequal lengths, so that the time of transit at one station will be different from the time of transit at the other.

The difference will enable the observers, when they come together and compare notes, to determine the difference in the lengths of the chords described by the planet, and consequently their respective positions on the solar disc, and so the amount of their separation.

The measure of this separation, or the apparent displacement of Venus on the sun's disc, is what is required.

It is almost utterly impossible to obtain the measure of this displacement with sufficient accuracy, owing to the errors of refraction caused by the atmospheres of Venus, the Earth, and the Sun.

A great drawback with this method, too, is the extreme rarity of the transits.

The best and most available way, however, of finding the sun's distance is the diurnal method of taking successive morning and evening observations from the same spot, and by the same person, upon the Minor Planets, the rotation of the earth supplying the necessary difference in the points of view.

This method is the one now most used, and has a number of advantages. About a dozen of these small bodies are sufficiently bright and approach near enough to the earth when on the same side of the sun with it (opposition) for this purpose.

One very great advantage here enjoyed is that the planetoids have no sensible discs, appearing simply as points of light, and thus favor exact measurement.

Another advantage is the unity of performance. Many small errors are avoided in the work being done by a single pair of eyes, and with the same optical instruments.

These oppositions occur, too, frequently, and no elaborate preparations are necessary for the work.

Heliocentric or Annual Parallax.—The Heliocentric or Annual Parallax of a heavenly body is its apparent displacement as seen from the earth and the sun, or is the magnitude of the radius of the earth's orbit as seen from the distant body.

This base line is 92,500,000 miles, and viewed from the distance of most of the fixed stars, has no magnitude whatever.

Stellar Parallax.—To find stellar distances this heliocentric or annual parallax is alone available.

There are principally two methods employed in determining the annual parallax of stars, the absolute and the relative or "differential."

In order to obtain the absolute parallax of a star, its polar distances are regularly measured for a long period, and from the mean of all the observations the displacement due to parallax is computed.

The errors in this method arising from the variation in the refracting powers of the atmosphere, and from the expansion and contraction of the meridian circle or transit instrument by changes of temperature, would almost entirely vitiate so small a quantity as the parallax of a star.

In the differential method, by which most of the stellar distances now known have been computed, the observer chooses two stars so close together as to be in the same field of view of his telescope.

One of these stars is known from its proper motion to be much nearer than the other. The separation of the stars caused by the earth travelling around its orbit is measured as accurately as possible with the micrometer, and half the sum is the relative or differential parallax.

In this case the parallax of the more distant star is assumed to be zero.

In the differential method the effects of refraction may be said to be eliminated, as both the stars are displaced through refraction by almost the same amount.

Magnitude of Celestial Bodies.—The magnitude of any heavenly body having a sensible disc can be easily determined when its distance is known.

The apparent diameter of the distant body is measured with as much precision as possible, and divided by two to obtain the apparent radius.

We thus have a right-angled triangle, with the hypothenuse, which is the body's distance, and the angle opposite the perpendicular, which is the apparent radius, to find the perpendicular.

When the radius of a spherical body is known, its other dimensions can be ascertained.

Refraction.—It is a well-known principle in optics that when a ray of light passes from a rare to a more dense medium it is bent towards the perpendicular or vertical.

The matter composing our atmosphere grows more and more dense as the earth's surface is approached.

The light-rays coming in from space in an oblique direction are therefore constantly bent more and more, until they take the form of a curve, and we see the object in the direction of a tangent to this curve.

This atmospheric refraction affects alike the light-rays from the most distant as well as nearer bodies.

The waves of light from bodies in the Zenith, or directly overhead, are not in the least influenced by refraction, as they are already in the line of the vertical.

The nearer bodies are to the horizon the more strongly is their light refracted, because its beams are most oblique to the vertical, and must journey through the greatest stretch of atmosphere.

The amount of refraction at the horizon is thirty-four minutes; at a height of one degree it is but twenty-four, and at an elevation of forty-five degrees it is only about one minute.

Thus, in observing the position of the heavenly bodies correction must be made for refraction, and it is of the utmost importance that the body be observed when as high as possible above the horizon.

As the mean apparent diameters of the sun and moon are respectively thirty-two and thirty-one minutes, and the refraction at the horizon thirty-four, it follows that these bodies are entirely visible both after actually setting and before rising.

It is refraction that gives to the sun and moon their oval shapes when close to the horizon.

Refraction increases so rapidly towards the horizon that the lower limbs of these luminaries are raised by its action much more than the upper ones, and their discs consequently assume an oval figure.

In most cases the contraction of the vertical diameter of the sun amounts to six minutes of arc.

Twilight.—Twilight has an atmospheric origin, and is occasioned by the refraction and reflection of sunlight in its passage through air.

The phenomenon, however, is principally due to reflection. The air reflects to us some portion of light when the sun is as far below the horizon as eighteen degrees.

At the equator the sun ascends or descends through eighteen degrees in one hour and twelve minutes.

At the equator the path of the sun is nearly perpendicular to the horizon, and it travels over this space rapidly; but when the sun's path is more oblique it takes the luminary a longer time to pass over the space that carries it eighteen degrees below the horizon, and the twilight is lengthened. In one case the sun goes vertically down, and in the other it moves along a slant.

Near the poles of the earth the sun is within eighteen degrees of the horizon during two-thirds of the year, and so these polar regions enjoy an almost perpetual twilight.

The peculiar property the air has of dispersing light in all directions is what renders objects on the earth out of direct sunshine visible to us.

Were it not for this property of the atmosphere, everywhere beyond the reach of the direct rays of the sun would be as dark as night.

A fair degree of humidity increases the transparency of the atmosphere.

When, particularly in hot weather, the stars look unusually bright, remote objects appear uncommonly distinct, and the sky's azure is unwontedly deep, it is the herald of approaching rain.

Aberration.—The aberration of light is the apparent displacement of a heavenly body caused by the combined effects of the earth's motion and the velocity of light.

Light travels very rapidly, but still requires time for its passage. During the time occupied by the light-ray in reaching us from a heavenly body the earth travels some distance in its path.

The true place of a star is not where we observe it, but at a slight angle in the direction of the earth's motion.

The amount of aberration is the proportion between the respective velocities of the earth and light, and is very small indeed. Light is nearly ten thousand times more rapid than the earth in its flight.

This apparent alteration of a body's place due to aberration is then extremely small; still, in delicate measurements it must be allowed.

The heavenly body returns to its original position at the end of a year, or revolution of the earth in its orbit.

The phenomenon was discovered by Bradley in 1729 while endeavoring to find stellar parallaxes.

Latitude.—The Latitude of a place is its distance north or south of the Equator, measured on the arc of a great circle passing through the place and the Pole, and perpendicular to the Equator.

Latitude is reckoned from 0° to 90°; the latitude of the Equator being 0°, and of the Pole 90°.

When an observer is on the Equator the Pole is in his horizon, and if he travels one degree northward from the Equator, the North Pole will rise one degree above the horizon.

The latitude of an observer is then represented by the elevation of the Pole above the horizon.

If the Polar Star were situated exactly at the celestial Pole, its altitude as seen from any place would be the latitude of the place, and to find the latitude it would only be necessary to determine the star's elevation.

The Polar Star is not, however, precisely at the celestial Pole, but makes a small circle daily around it.

By observing the greatest and least meridian altitudes of the Polar Star, or, for that matter, of any circumpolar star, and taking half the sum, we obtain the latitude of a place, correction being made for refraction.

Longitude.—Longitude is reckoned along the Equator, being the portion of that great circle intercepted between the first assumed meridian and the meridian of the place.

The Meridian of a place is a great circle of the heavens passing through both celestial poles, and through the zenith of the place.

With us the First Meridian is sometimes assumed to be Washington, and sometimes Greenwich.

The Longitude is counted 180° east and west of the first meridian.

Longitude may be reckoned in time as well as in degrees.

The earth rotates through 360° in twenty-four hours, and so 15° are equal to one hour, and one degree to four minutes.

If we know the difference in time between the first meridian and our own, we can easily reckon our Longitude by adding one degree for every four minutes if we are west, or subtracting if we are east, of the assumed first meridian.

The difference of time between the places can be determined by means of the electric telegraph. The observers having, by the aid of transit instruments, perfectly corrected their clocks, can, by a telegraph signal, immediately perceive the difference in local time between the places, and make the computation accordingly.

There are a number of other ways of finding the Longitude of a place with the aid of the *Nautical Almanac*, such as by Solar and Lunar Eclipses, Lunar distances, Occultation of Stars, and Eclipses of the Satellites of Jupiter.

CHAPTER XVI.

MECHANISM OF THE WORLD.

"God of the rolling orbs above!
Thy name is written clearly bright
In the warm day's unvarying blaze
Or evening's golden shower of light;
For every fire that fronts the sun,
And every spark that walks alone
Around the utmost verge of heaven,
Was kindled at Thy burning throne."
—Peabody.

God is, indeed, plainly visible in His creation. On all sides, everywhere, are the most palpable evidences of omnipotence and infinite wisdom. Truly "the heavens declare the glory of God, and the firmament showeth His handiwork."

Who but our Creator could impose upon inert matter the beautiful and sovereign laws of gravitation and motion? Who but He could endow light and heat and electricity with their wondrous properties?

In the mighty magnitudes of the heavenly bodies, as in their awful distances and velocities, what omnipotence! What wisdom in the singularly striking adaptation of means to their ends everywhere apparent in creation!

The distance of the earth from the sun is just the most fitting for the best growth of our animals and plants, confining the heat of the sun within narrow and suitable bounds.

The change of seasons is just precisely sufficient to produce a proper variety of animal and vegetable life. What could be more happy than the division of day and night?

The tides are just within the limits to preserve the waters from corruption and not to overflow and deluge the earth.

Look at the multiple beneficent uses of the atmosphere. It supports the life of animals and plants, the one by supplying oxygen, the other carbon. What would destroy the animal vivifies the plant.

It supports combustion. It tempers the heat and the cold. It prevents, by its pressure, all fluids on the earth's surface from passing immediately away in vapor. It nourishes the earth with rain, diffuses the sunbeams, and conducts sound.

What a nice adjustment of the solar system for the maintenance of its stability! If the orbits of the great planets had been more eccentric or more inclined, the system would fall to pieces. Did all not revolve in the same direction, it would be fatal to stability.

The orbits of Mercury, Mars, and the planetoids are much more eccentric than those of the great planets. The eccentricity of the paths of Mercury, Mars, and the planetoids can work no mischief to the system owing to their small masses.

Had the paths of the great planets been equally eccentric, serious derangement would result; the eccentricity of the earth's orbit would be gradually increased and the nature of its year completely changed; the moon might be precipitated upon us, or the planets might approach very near and draw the earth away from the sun. "We might have years of unequal length, and seasons of capricious temperature; planets and moons, of portentous size and aspect, glaring and disappearing at uncertain intervals; tides, like deluges, sweeping over whole continents, and perhaps the collision of two of the planets and the consequent destruction of all organization on both of them."

Nebular Hypothesis.—Concerning the arrangement or Mechanism of our system of worlds two opinions are worthy of consideration.

One is that the Solar System, and, indeed, the Cosmos, were created in their present shape instantly, out of nothing.

The second is that the present form is the result of an arrangement of materials which were before "without form and void."

There are a number of hypotheses purporting to account for the present harmonious mechanism of the planetary scheme.

Among them the most beautiful and famous is the Nebular Hypothesis of Laplace. The nebular hypothesis treats only of the transformations, and does not concern itself with the origin of matter.

Laplace begins by supposing the sun to have a more or less dense nucleus, surrounded by a rare, elastic atmosphere of vast extent.

He considers this nucleus as either solid or so dense, compared with the atmosphere, as to be relatively solid, and to contain by far the greatest amount of the body's mass.

He assumes, for the sake of convenience, the form of this nucleus to be already reduced to that of a spheroid, differing but slightly from a sphere; but the shape of the atmosphere's bounding surface he leaves to be determined solely by the resultant of the centrifugal and gravitating forces, springing from any given mass and velocity of rotation that the body can have.

The nucleus and atmosphere are rotating on an axis. Laplace calls the distance of that portion of the atmosphere from the axis where the centrifugal force just balances gravity, the Centrifugal Limit.

Laplace then demonstrates mathematically that at the centrifugal limit of the atmosphere of a rotating body, over the equator, the equatorial radius is to the polar precisely as 3 to 2.

When, then, the axial motion of the sun became so great that centrifugal force caused its atmosphere's equatorial axis to be to its polar as 3 to 2, the outer portion of the atmosphere would leave the sun.

Laplace supposed that owing to excessive heat the atmosphere of the sun extended beyond the orbits of all the planets, and that it has successively contracted up to its present limits.

He conjectures that the planets were formed at the successive centrifugal limits of the solar atmosphere by the condensation of the zones of vapor which, in cooling, it had been obliged to abandon in the plane of its equator.

"The atmosphere of the sun," he says, "could not extend outward indefinitely. Its limit is the point where the centrifugal force, due to its axial motion, balances gravity.

"Now, in proportion as its cooling causes the atmosphere to contract and to be condensed towards the sun's surface, the motion of rotation must increase. For, by virtue of the principle of areas, the sum of the areas described by the radius-vector of each molecule of the sun and of its atmosphere, when projected on the plane of his equator, being always the same, the rotation ought to be more rapid when these molecules are brought nearer the sun's centre. The centrifugal force, due to this increased motion, thus becoming greater, the point at which gravity is equal to it approaches nearer the sun's centre.

"By supposing, therefore, what it is very natural to admit, that the sun's atmosphere at any epoch had extended up to this limit, it would be necessary, on further cooling, for the atmosphere to abandon the molecules situated at this limit and at the successive limits produced by the increase of the sun's rotation.

"These molecules, thus abandoned, have continued to circulate around the sun in the same direction as before, since their centrifugal force was just balanced by their gravity towards the sun.

"But this equality of centrifugal force and gravity not taking place with regard to the atmospheric molecules placed on the parallels to the solar equator, these latter molecules, by their gravity, will follow the atmosphere in proportion as it is condensed, and will not cease to belong to it until by their motion they have reached the equator.

"Let us consider now the zones of vapor successively abandoned. These zones ought, most probably, to form by their condensation and the mutual attraction of their molecules, various concentric rings of vapor revolving around the sun. The mutual friction of the molecules of each ring ought to accelerate those moving more slowly, and retard the swifter, until they should all have acquired the same angular motion about the sun.

"Hence, the real velocity of the molecules farthest from the sun will be the greatest.

"The following cause ought to contribute also to this difference of velocity. The molecules of the ring most distant from the sun, and which, by the effect of cooling and condensing, are brought nearer, so as to form the outer portion of the ring, have always described areas proportional to the time; since the central force by which they are animated has been constantly directed towards the sun's centre.

"Now, this constancy of areas requires an increase of velocity in proportion as they approach the centre of motion. It is evident that the same cause ought to diminish the velocity of those molecules which, by the cooling and contracting process, are carried outwards to form the inner part of the ring.

"If all the molecules of one of these vaporous rings had continued to condense without separating, they would have formed at last a liquid or a solid ring.

"But the regularity which such a formation requires in all parts of the ring, and in their rate of cooling, ought to render this phenomenon extremely rare.

"Hence the Solar System offers but a single example of it; namely, that of the rings of Saturn. Almost always each vaporous ring ought to be broken into several masses, which, moving with nearly the same velocity, have continued to revolve around the sun at the same distance from him.

"These masses ought each one to take on a spheroidal form, with a motion of rotation in the same direction as their motion of revolution around the sun; since their molecules nearest to him had less velocity than those farthest from him.

"They must, therefore, have formed so many planets in a vaporous condition. But if one of them had been large and powerful enough to successively reunite by its attraction all the others around its own centre, the vaporous ring will have been thus transformed into a single spheroidal vaporous mass revolving around the sun nearly in the plane of his equator, with a nearly circular orbit, and with its motion of rotation generally in the same direction with that of its revolution around the sun.

"This last case has been the most common; but the solar system offers to us an example of the first case in the four small planets revolving between Mars and Jupiter, unless we suppose, with Olbers, that they formed at first a single planet which some strong explosion has divided into several parts, animated by different velocities.

"If, now, we follow the changes which further cooling ought to produce in the planets consisting of vapor, the formation of which we have just considered, we shall see a nucleus begin at the centre of each of them, and see it grow continually by the condensation of the atmosphere which surrounds it.

"In this state the planet perfectly resembles the sun in the nebulous condition which we have been considering. Its cooling ought, therefore, to produce, at the different centrifugal limits of its atmosphere, phenomena similar to those which we have described; that is to say, rings and satellites revolving around its centre in the direction of its motion of rotation, and the satellites rotating also in the same direction on their axes.

"The regular distribution of the mass of Saturn's rings around his centre, and in the plane of his equator, results naturally from this hypothesis, and without it becomes inexplicable. These rings appear to me to be the ever-existing proof of the former extension of Saturn's atmosphere, and of its successive contractions.

"Thus, the singular phenomena of the small eccentricities of the orbits of the several planets, and those of their satellites, or their almost circular orbits, the small inclinations of these orbits to the sun's equator, and the identity of the motions of rotation and revolution of all these bodies with that of the sun's rotation, flow from the hypothesis which we propose, and give to it a great probability, which may be still further increased by the following considerations:

"All the bodies which revolve around a planet, having been formed, according to this hypothesis, by the zones which its atmosphere has successively abandoned, and the planet's motion of rotation having become more and more rapid, the duration of this rotation ought to be less than those of the revolution of these different bodies. This must be true, likewise, for the sun in comparison with the planets. All this is confirmed by observation.

"The duration of revolution of Saturn's nearest ring is, according to Herschel's observations, 0.438d., and that of Saturn's rotation is 0.427d. The difference, 0.011d., is small, as it ought to be; because the part of Saturn's atmosphere which the loss of heat has condensed upon the planet's surface since the formation of this ring being small, and coming from a small height, it ought to have produced but a small increase of the planet's rotation.

"If the Solar System had been formed with perfect regularity, the orbits of the bodies which compose it would have been perfect circles, whose planes, as well as those of the different equators and rings, would have coincided exactly with the sun's equator. But we can conceive that the innumerable varieties which ought to have prevailed in the temperature and density of the several parts of these great masses have produced the eccentricities of their orbits and the deviations of their motions from the plane of the sun's equator.

"In our hypothesis the comets are strangers to the planetary system. Considering them, as we have done, as small nebulæ wandering from one solar system to another, and formed by the condensation of nebulous matter so profusely scattered throughout the universe, it is evident that when they arrive at that part of space where the sun's attraction predominates, he compels them to describe elliptical or hyperbolic orbits. But their velocities being equally possible in all directions, they ought to move indifferently in all directions, and under all inclinations to the ecliptic, which is conformable to observation. Thus the condensation of nebulous matter, by which we have explained the motions of rotation and revolution of the planets and satellites in the same direction and in planes of small inclination to each other, explains equally why the comets depart from this general law."

Reasoning backward from the point where he assumed, for convenience, the sun to be a dense nucleus with a hot extensive atmosphere, Laplace supposes the radiant orb, in a more primitive state, to resemble those nebulæ shown by the telescope to be composed of a brilliant nucleus surrounded by a nebulosity which, by condensing towards the surface of the nucleus, transforms it into a star.

Judging from analogy, he supposed the stars all formed in this way by condensation from nebulous matter. Each condition of nebulosity was preceded by other conditions, in which the nebulous substance was more diffused, and the nucleus less luminous and less condensed. In this way he reaches a condition of nebulosity barely existing.

Because our planets and satellites are the offspring of the same atmosphere in whose primitive motion all partook, Laplace points out as proofs of the truth of his hypothesis: that the movements of the planets are all in the same direction, and nearly in the same plane;

That the motions of the satellites are in the same direction as those of the planets;

That the rotations of these different bodies, and of the sun, are in the same directions as their orbital motions, and in planes that vary but little from each other;

That the paths of both planets and satellites are nearly circular, or of small eccentricity;

That, contrarily, the orbits of comets are of great eccentricity, and of every inclination to the ecliptic, and that their motions are in all directions.

Laplace puts forth his hypothesis with much diffidence, as the merest speculation.

Shortcomings of the Hypothesis.—Laplace assumes nearly everything. He does not explain the origin of the primitive nebula, nor how it received its first motion.

He fails to show how the primitive solar atmosphere came by just such fitting properties of not being too viscous nor too fluid, but just of the proper consistency and elasticity to fly off under the influence of a certain amount of velocity. Nor does he give any reason why this atmosphere condensed into beautiful planets instead of meteoric stones, as would be the more likely; nor how it came to be endowed with suitable degrees of cohesion and adhesion, and the properties requisite for contraction and condensation.

Laplace likened the Solar System in its primitive state to the distant nebulæ, which he looked upon as forming star systems, and external to, and quite distinct from, the sidereal universe.

But these nebulæ are not external galaxies, nor distinct from the sidereal system, but are indeed part and parcel of it.

From the examination of the great irregular nebula surrounding Eta Argus, the great Orion nebula, the nebulæ of the Nubeculæ, and similar nebulæ, it cannot be doubted that a real and close association exists between the stars and nebulæ, and that they really constitute but a single system.

According to Laplace, the primary must rotate on its axis in less time than its satellite revolves about it.

The inner satellite of Mars, on the contrary, revolves about him three times while he is rotating once. Here is an observed fact, opposing the hypothesis.

The sun has by tidal action somewhat retarded the axial velocity of Mars, but certainly not to this extraordinary extent.

It is admitted that the earth's axial motion has been but little affected by solar tidal action. Solar tides on Mars could not, then, have produced such wondrous effects.

If the mass of Mars be less than the earth's, his diameter is also much less, and, other things being equal, tidal action is proportioned to the diameter of the body acted upon. Mars, too, is one and a half times more distant than the earth from the sun.

One of the main pillars of Laplace's hypothesis is the uniformity of the motions, both axial and revolutionary, of the planets and satellites in the same direction from west to east. Here again is an observed fact against the hypothesis. The satellites of Uranus, and that of Neptune, are known to have a retrograde movement.

There is a great dynamical principle known as the conservation of the "moment of momentum." This conservation of the moment of momentum differs entirely from what is known as the conservation of energy.

The energy of the solar system can be transformed into heat, and a portion of it constantly dissipated and lost in space, but no action of the system itself can ever alienate a single iota of the moment of momentum.

The relative distribution of the moment of momentum may be altered, but the total amount, barring external influence, can never be changed.

If we multiply Jupiter's mass by his angular orbital motion in one second, and the product by the square of his distance from the sun, we obtain Jupiter's orbital moment of momentum.

If we multiply Jupiter's mass by his angular rotatory motion in one second, and the product by the square of a line depending on his constitution, we have his rotational moment of momentum.

Similarly the moments of momentum of the other planets are deduced.

If we multiply the sun's mass by his angular rotatory motion in one second, and the product by the square of a line depending on his constitution, we obtain his rotational moment of momentum.

Professor Ball gives the following distribution of the moment of momentum in the Solar System, the total being taken as 100:

Orbital moment of momentum of Jupiter.....	60
Orbital moment of momentum of Saturn......	24
Orbital moment of momentum of Uranus......	6
Orbital moment of momentum of Neptune	8
Rotational moment of momentum of the Sun..	2
Total..............	100

The other bodies are not considered, their moment of momentum being comparatively infinitesimal.

Professor Ball says: "It might be hastily thought that, just as the moon was born of the earth, so the planets were born of the sun, and have gradually receded by tides into their present condition. We have the means of inquiry into this question by the figures just given, and we shall show that it seems utterly impossible that Jupiter, or any of the other planets, can ever have been very much closer to the sun than they are at present."

Above all, it seems utterly impossible that Jupiter could have received his orbital moment of momentum from the sun.

Laplace's hypothesis places the centrifugal limits of the abandoned portions of the revolving glowing atmosphere of the sun widely apart. After abandoning the first vaporous ring, the atmosphere contracts to nearly one-half its primitive bulk before throwing off another. The abandonment of each ring was followed by an immense atmospheric shrinkage.

This would demand such great cohesion in a glowing mass of vapor as it is difficult to concede it possessed. It would seem to be more in accord with the character of a gaseous body that, when the centrifugal limit was reached the first time, the outer mass, under the influence of centrifugal force, would partially separate from the portions next to it; then these would separate next, and so on. In this way, instead of a series of rings, there would be a constant dropping off of matter from the outer portions, producing an almost infinite number of concentric rings, all joined together. Thus, there would result a meteoric instead of a planetary system. This is the objection of Professor Kirkwood.

Professor Newcomb considers that the rings were all thrown off together, and that the inner and smaller bodies are, if anything, the older.

Faye thinks that the outer planets were formed last.

Thus it appears that Laplace's hypothesis is far from being established, if indeed it has not altogether failed.

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