ILLUSTRATED LONDON ASTRONOMY.

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THE ILLUSTRATED
LONDON
ASTRONOMY,

FOR THE

Use of Schools and Students.

BY

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WITH

NUMEROUS ILLUSTRATIVE DRAWINGS AND DIAGRAMS.

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PREFACE.

The study of Astronomy by young persons cannot be too highly commended; it expands the mind, raising it from the ordinary affairs of earth to the contemplation of the works of the Creator upon the grandest scale that man can behold them. In the heavens we every where witness the most astounding proofs of Almighty power and design; and if feelings of pride are induced by the advances which human thought and application have made in unfathoming the mysteries of the universe, those feelings must give way to others of a contrary character—of humility—when we reflect how small, how insignificant, a place is occupied by the earth on which we dwell, vast as it appears to us, amongst the infinity of worlds scattered through the firmament. Such should be the invariable result of a study of the sublime facts of Astronomy.

Thousands of years have rolled away since the Chaldean shepherds watched the stars while guarding their flocks by night—and yet how small our knowledge of them in the nineteenth century, compared with what there is to learn! Aided by the telescope, rapid advances have truly been made within the last three hundred years; but there is work for ages to come, ere man will rest content. "That which we know is little," exclaimed Laplace; "but that which we know not is immense."

In preparing the present work, which is specially intended for beginners, the author has endeavoured to give the most information in the fewest words, consistent with a clear understanding of the subject under treatment; to offer the most simple explanations of astronomical principles and phenomena; and, as far as practicable within the limits of the work, a description of the various heavenly bodies, according to the actual state of our knowledge respecting them. Without professing to have followed any particular plan of arrangement of his subjects, the author trusts they will be found to be introduced in such order, that the learner will experience no difficulty in comprehending them as he goes on.

It is intended that the *sense* rather than the words of the text should be expected by the teacher from the pupil.

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THE
ILLUSTRATED LONDON ASTRONOMY.

INTRODUCTION.

ASTRONOMY is that branch of natural science which treats of the heavenly bodies, describing their apparent and real magnitudes, distances, and motions, and the laws by which they are governed. The wonderful facts it reveals to us respecting the mechanism of the heavens, the grandeur and illimitable extent of the starry universe, and the beautiful harmony and regularity which prevail in the varied phenomena of the skies, have well entitled it to be called "the sublime science."

The determination of the apparent and real magnitudes and distances of the heavenly bodies, their orbits or paths in space, and every thing relating to description or observation, form what is called *Plane* or *Practical* Astronomy; the latter term is sometimes more especially applied to the management of astronomical instruments, and the explanation of the processes of calculation which attend their use.

The investigation of the *causes* operating in the motions and phenomena of celestial bodies constitutes *Theoretical* or *Physical* Astronomy; an abstruse and difficult study, which involves mathematical reasoning of the highest order, and is consequently suited only to the comprehension of the few.

In the present treatise we have to explain the principles of *Plane* Astronomy, and to place before the learner an outline of the most remarkable discoveries of ancient and modern times in this interesting science.

APPARENT MOTIONS OF THE STARS.

Suppose a person to have taken his station somewhere in this country soon after dusk on a clear winter evening, where his view of the heavens is uninterrupted by terrestrial objects.

The circle which limits his view on all sides is the *sensible horizon;* and an imaginary line passing through the north and south points of the horizon and the point immediately over his head (termed the *zenith*) is the *meridian* of the place.

If he regards with attention for some time the appearances of the stars, he will find that the greater number have an *apparent* motion from east to west; stars that were near his western horizon when he commenced his observations will have *set* or vanished below it, while others have *risen* in the east. After a few hours, he perceives a great change in the aspect of the heavens. One star, however, still retains to the eye the same place it before occupied, and round this one the rest appear to have been carried: it is the *Pole-star*. He notes the distance between this star and the north point of his horizon, which is the elevation of the pole, or the *latitude* of his station upon the earth's surface. Continuing his observations, he remarks that those stars which are at a less distance from the Pole-star than his north horizon never set or disappear below it, but pass under the pole towards the east; and observes in general, that the nearer a star is to the pole, the slower it appears to move; and therefore the smaller is the space over which it seems to pass in a given time. He discovers that the stars attain their greatest *altitude* or height above the horizon when they arrive at the meridian, the act of passing which is termed the *meridian passage* or *transit* of a star.

If he pursues his observations for several evenings, he probably finds that, while the stars generally retain their relative positions without further change than is produced by their apparent westerly motion, one or more of the brighter objects have really altered their places with regard to the others. These moving bodies are the *planets;* the others, which are infinitely more numerous, are called the *fixed stars;* a term that requires to be understood in a comparative rather than an absolute sense.

Suppose our observer, after a lapse of six months, to resume his station on a fine summer night, he immediately perceives a complete change in the aspect of the stars in his southern sky. New groups, of which he saw nothing before, now shine in place of the old ones. Turning to the north, he recognises many of the stars he had watched during the winter; but they have apparently travelled half round the Pole-star; and some of those groups of stars which at the time of his previous observations were nearly overhead, are now seen between the pole and the north horizon. The same apparent movements as before are, however, still going on, though the configurations of many of the stars are new to him.

The moon offers, at all times of the year, many points for his consideration. In the course of a month he traces her from the narrow crescent just visible above his western horizon, as she passes onward amongst the stars with an easterly motion, her illuminated face increasing until it becomes a perfect circle, and then again diminishing to a thin crescent in the eastern morning sky; and a few days later he again finds her in the west recommencing her journey in the heavens.

THE SYSTEM OF THE UNIVERSE.

By the *system of the universe* is understood the general arrangement of the heavenly bodies, so as to enable us to account for the appearances already described.

The system now known to be the true one, and universally received, is called the *Copernican*, or, less frequently, the *Pythagorean* system. Its main facts were taught by Pythagoras, a celebrated Greek philosopher, who flourished about 500 years before the Christian era; and his disciple Philolaus likewise supported its doctrines. But it is even probable that some of the principles of the received system were current amongst the ancient Egyptians, a nation which distinguished itself for its acquaintance with the science of astronomy.

About 350 years after Pythagoras, an erroneous theory of the universe was propounded by Claudius Ptolemy of Alexandria in Egypt, which, as it assigned to the Earth a more prominent and important place than the Greek system, prevailed almost exclusively for more than 1500 years, or until the true one was revived by Nicholas Copernicus of Thorn in Prussia about the commencement of the sixteenth century. Yet the rapid advances and discoveries of astronomy since the age of Copernicus have rendered necessary several additions and modifications in the plan of arrangement for which he contended.

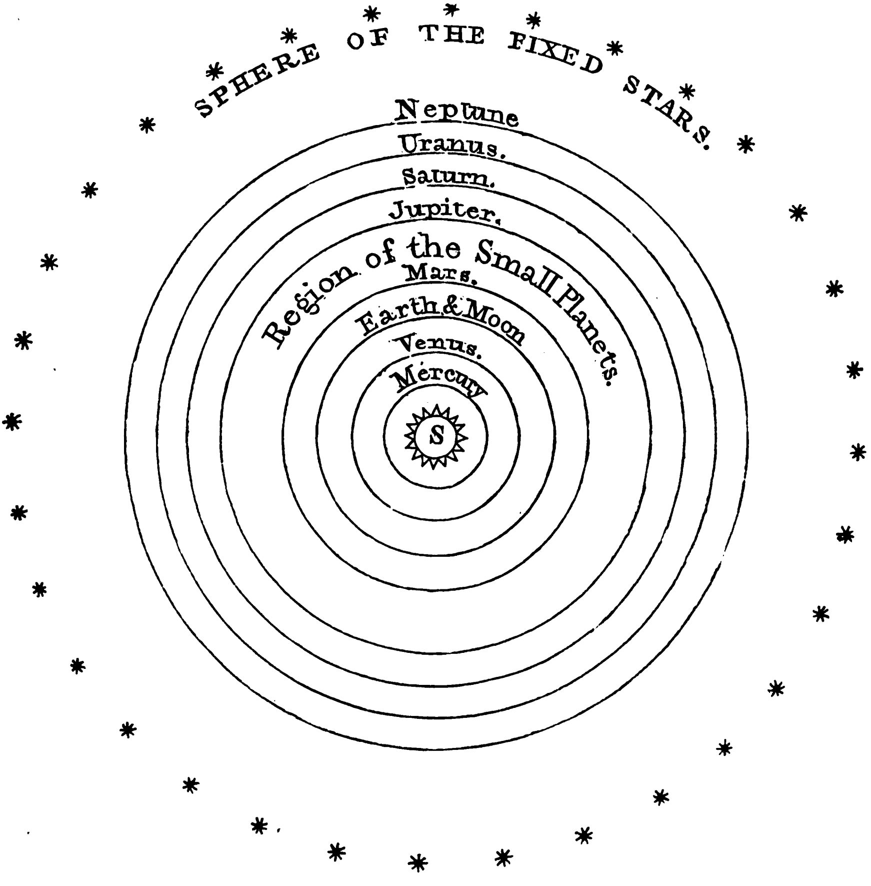

fig. 1. The System of the Universe.

The received system of the universe in its present comprehensive form is as follows (fig. 1): The Sun occupies the centre, which appears the most natural place for so great and splendid a body. Round him revolve the planets, in periods of different length and at various distances; the nearest completing a circuit in less time than the next in order of distance, and so on. Mercury is the first or nearest planet to the Sun, and Venus the second; they were both known to the ancients as far back as we have any records; their orbits, or the paths they describe, it will be seen, are within the Earth's, and for this reason they are termed *inferior* planets. Our globe is one of the planets, and is accompanied in its course round that luminary by the Moon, which revolves about the Earth as the latter pursues her course round the Sun. Mercury, Venus, the Earth, &c. are called *primary* planets, but the Moon is termed a *secondary* planet or *satellite;* the distinction being, that the former acknowledge the Sun for the centre of their motions, while the Moon occupies a less distinguished position, her central body being the Earth, which is itself a planet.

Beyond the Earth we have the planet Mars, also known to the ancients: then follows the region of the small planets, a numerous class of bodies, discovered since the beginning of the present century. The engraving indicates their position in the system, but it would have only tended to confuse, had their paths about the Sun been introduced; none of them, however, approach so near the Sun as Mars, nor attain the orbit of Jupiter, the next distant planet. Jupiter was recognised by the ancients; he has four moons or satellites, detected since the invention of the telescope. Saturn comes next, and is the most distant of the planets known to the ancient world, which, as we have seen, were five in number, exclusive of the Earth. This body is attended by no fewer than *eight* little telescopic moons, and is surrounded by several luminous rings, the results of modern discovery. Uranus follows Saturn, and was found in 1781 by our great astronomer, the late Sir William Herschel: this planet has a number of moons, four at least, possibly many more. Neptune, also a modern discovery, and one of a very remarkable and unprecedented character, completes the list of planets.

All the planets which revolve in orbits exterior to, or more distant from, the Sun than the Earth's path, from Mars to Neptune inclusive, are called *superior* planets. An inferior planet is always nearer to the central Sun than the Earth, and revolves in a shorter time; while a superior planet is constantly further from it than our globe, and requires a longer period to perform its revolution.

At distances immensely greater than that which separates Neptune from the Sun, are the *Fixed Stars,* which surround the planetary system in all directions. A small engraving can convey no adequate idea of relative distances, such as those we meet with in the study of astronomy. It must therefore be understood that fig. 1 is intended to illustrate the general arrangement and order of the Sun, planets, and stars, and by no means as a scale of distances. Neptune is thirty times further removed from the Sun than the Earth, and the nearest of the fixed stars is at least seven thousand times more distant than Neptune; but these subjects will engage our attention after the fundamental principles of the science have been explained.

The planets all move round the Sun in the same direction.

A class of bodies termed *Comets,* which revolve about the Sun in paths of an oval or elliptical form, intersecting the orbits of the planets under various conditions, requires to be mentioned as forming part of the system, of which the Sun is the central body.

FIGURE OF THE EARTH.

The form of the Earth is very nearly that of an orange; it is not therefore a perfect sphere, in which case the diameter in every position would be the same.

Many proofs may be advanced that the Earth is round. Ships have left a port, and after sailing in the same direction, excepting such deviations as were unavoidable through the intervention of land, have ultimately arrived at the port from which they set out. If we watch the vessels on the sea-coast as they recede from the shore, another indication of the round figure of our globe is afforded; we first lose sight of the hull of a ship, then of the lower masts, and finally, of the highest sails and masts, as the vessel sinks below the horizon in sailing for its destination. In addition to these simple proofs, there are many others less easily understood by the beginner.

REVOLUTION OF THE EARTH UPON HER AXIS. DAY AND NIGHT. APPARENT MOTIONS OF THE STARS EXPLAINED.

The Earth revolves from west to east, about an imaginary line called her *axis*, in the space of one day. The extremities of the axis are termed the *north* and *south* terrestrial *poles*; and if we suppose it extended to the stars, it indicates the *poles of the heavens*. Equi-distant from the poles on the surface of the Earth is the great circle called the *equator*, which divides our globe into two equal parts or hemispheres; and an extension of its plane to the starry sphere traces out the *celestial equator*, or *equinoctial* as it is sometimes called.

As consequences of the Earth's diurnal revolution, the heavenly bodies *appear* to have that motion from *east to west* to which allusion has already been made; hence the cause of day and night: for suppose S to be the Sun, E the Earth, turning upon her axis N O from *west to east* in the direction of the arrows, half her surface only is illuminated at one time by the Sun. To a person at B the Sun is in the horizon, and day commences, the luminary appearing to rise higher and higher in the heavens with a westerly motion, as the observer is carried forward by the Earth's diurnal rotation to C, when he has the Sun in his meridian, and it is consequently noon. The Sun then begins to decline in the sky until the spectator arrives at D,

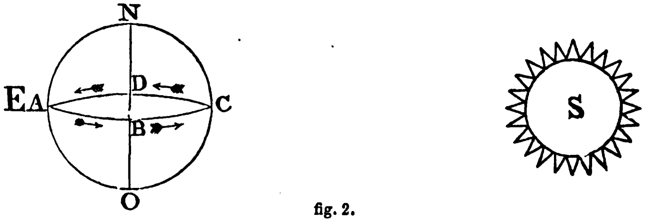

fig. 2.

when it sets, or is again in the horizon on the west side, and night begins. He moves on to A, which marks his position at midnight, the Sun being then on the meridian of places on the opposite part of the Earth, and he is then brought round again to B, the point of sun-rise, when another day commences.

It has been before remarked that many of the stars do not appear to rise and set, but pass round the pole of the heavens as a centre, and are continually above the horizon. To explain how this happens we must have recourse to fig. 3, where O is the place of a person upon the Earth's surface, S Z P N his meridian, S N the horizon, P and R the north and south poles of the heavens respectively, Z the zenith, and E Q the celestial equator. Now P N, it will be observed, is the elevation of the north pole above the horizon, or the latitude of the place. Suppose a star to be seen from the Earth on the meridian *below* the pole at *g*, as our globe revolves upon its axis in the direction E Q, the star appears to travel on through the small circle to *h*, when it is again on the meridian *above* the pole; it continues its course along the dotted line to *g*, and is once more on the meridian, having made a complete circuit round the Pole-star (which is apparently without motion), but has not descended below the horizon of the spectator; and it is easy to see that the same will happen with all stars whose distances from the pole are less than P N or the latitude of the place. A star further from the pole, as, for instance, at *e*, and above the equator, will rise at *d* and set at *f*, so that during a considerable part of its circuit it is invisible to the observer at E; and this holds good with a star at *b*, below the equator, which rises at *a*, and sets at *c*, excepting that its visible course is evidently much shorter than that of the former at *e*. A star upon the equator remains as long above the horizon as it does below it, or 12 hours in each case, being half the length of the Earth's diurnal revolution.

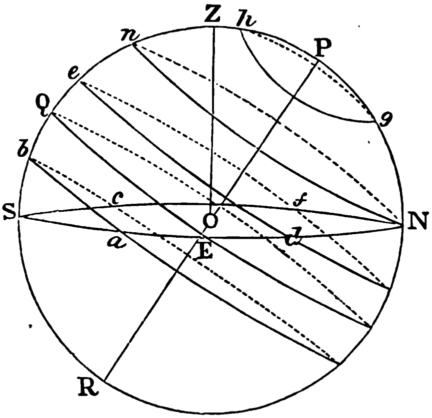

fig. 3.

Geographers divide the circumference of the earth into 360 degrees; astronomers do the same with the heavens. The angular distance of a star from the celestial equator is called its declination, and is counted on from 0° to 90° towards each pole, being considered *north* or *south*, according as we reckon towards the *north* or *south* pole.

Z N and Z S measure 90°, or one fourth of the circumference, and therefore the distance between the zenith and the pole (Z P) will be equal to 90° less the latitude of the place; and since the celestial equator is always equidistant from the poles; dividing the starry sphere into two equal parts, P Q will likewise measure 90°; hence as S Z N is 180°, Z Q is equal to P N, and Z P to Q S, or the distance between the zenith and the equator is equal to the elevation of the pole or the terrestrial latitude, and the distance between the zenith and the pole is equal to the greatest elevation of the equator above the horizon. S R is the depression of the south pole of the heavens below the same, and is also equal to the latitude of the place. Bearing these facts in mind, we learn as a general rule, applying to our own station upon the earth's surface, that all stars whose distances from the north pole are less than the latitude of the place never rise or set, but remain continually above the horizon : all others whose distances from the opposite pole are less than the same degree of latitude never become visible, while stars included between these limits rise and set ; their daily courses across the heavens or *diurnal arcs* being greater or less than 12^h, according as they are situate above or below the equator, or have north or south declination.

Modifications of this rule are required for places in the southern hemisphere, but they are easily supplied after a little consideration of figure 3.

To a person placed at either pole of the earth, the stars would not appear to rise and set, but would describe circles parallel to his horizon.

THE ECLIPTIC. EQUINOXES. ZODIACAL SIGNS. RIGHT ASCENSION AND DECLINATION. CELESTIAL LONGITUDE AND LATITUDE.

The Earth accomplishes a revolution round the Sun in the course of a year, and during the whole of this time her axis continues directed to the same point in the heavens.

We have seen that on the Copernican theory of the universe the Sun is really fixed in the centre of the system ; but the annual motion of the Earth causes him to appear to trace out in the heavens a great circle called the *ecliptic*, which coincides with the orbit of the Earth. The ecliptic cuts the celestial equator in two points, called the *equinoxes*, and is inclined thereto at an angle of 23½°, which is consequently the measure of the inclination of the Earth's axis to that of her orbit or the ecliptic, and is termed by astronomers the *obliquity of the ecliptic.*

The ecliptic is divided into 360°, and again into twelve equal parts of 30°, called *signs.* A belt of the heavens, extending 9° on each side of the same, is called the *zodiac*, within which the paths of all the larger planets appear to lie.

The zodiac is of very high antiquity, having been used amongst the ancient Egyptians, Hindoos, and other nations, as far back as we have any records. The stars which are comprised within this belt are formed into twelve groups or *constellations*, corresponding with the twelve signs, and each is represented by some figure, as that of an animal, &c., to which the configurations of the stars within it are supposed to bear some resemblance : the similarity, however, is very small, except in one or two cases. We here take occasion to remark that the subdivision of the stars into constellations is extended over the whole heavens—as will be described more fully in another place.

The following are the Latin and English names applied as well to the twelve signs as to the constellations of the zodiac ; also the symbols by which the former are distinguished :

♈	Aries	the Ram.	♎	Libra	the Balance.
♉	Taurus	the Bull.	♏	Scorpio	the Scorpion.
♊	Gemini	the Twins.	♐	Sagittarius	the Archer.
♋	Cancer	the Crab.	♑	Capricornus	the Goat.
♌	Leo	the Lion.	♒	Aquarius	the Water-bearer.
♍	Virgo	the Virgin.	♓	Pisces	the Fishes.

The equator is divided into 360°, and further into 24 hours, called hours of Right Ascension, measuring 15° each.

The commencement or *first point of Aries* coincides with that equinox where the Sun in the ecliptic crosses the equator, going north, and is adopted as a starting-point from which to reckon celestial distances.

The right ascension of a heavenly body is its angular distance from the first point of Aries, *counted on the equator* either in degrees or the equivalents in time, reckoning 15° to one hour, and proportionally for minutes and seconds. In the former mode of reckoning we have the right ascension in *arc;* and in the latter, the right ascension in *time.* If the declination of a star be given as well as its right ascension, we know its place in the heavens, for we have the distance from the equator, which is always expressed in degrees, minutes, and seconds, and the distance, measured on the equator, from the first point of Aries, which may be written in time or in arc:—thus, it amounts to the same thing to say that the right ascension of a star is 16^h 3^m, or that it is 240° 45′, because 16 multiplied by 15, the number of degrees in one hour, gives 240 for the degrees; and 3 multiplied by 15 gives 45 for the minutes.

The ecliptic is also used as a means of indicating the places of the stars. The angular distance of a heavenly body from the first point of Aries, *counted on the ecliptic,* is called its *longitude;* a term which must be carefully distinguished from longitude in geography. It is always expressed in degrees and minutes, *i.e.* in arc instead of time, and is usually counted on from 0° to 360°, the signs having gradually fallen into disuse on account of the unnecessary trouble they give in astronomical calculations. The distance of a star from the ecliptic north or south is its *latitude;* a term which is also to be understood in a very different sense to that in which it is employed in geography. The longitude and latitude of a star being given, its position in the heavens is known.

THE SEASONS.

The inclination of the Earth's axis to her annual path is the cause of that most important succession of seasons—Spring, Summer, Autumn, and Winter, on which mankind depend for the multifarious produce of the earth, necessary for the support and enjoyment of life. The simplicity with which the seasons are explained by the revolution of the Earth in her orbit and the obliquity of the ecliptic, may certainly be adduced as a strong presumptive proof of the correctness of the principles already advanced; for on no other rational suppositions with respect to the relations of the Earth and Sun, can these, and other as well-known phenomena, be accounted for.

In fig. 4, let A, B, C, D represent four positions of the Earth in her annual path round the Sun at S; P Q in each figure is her axis; P the north and Q the south pole; E F is the Earth's equator inclined to her orbit, or to the ecliptic, 23½°.

When the Earth is at A, the north pole (P) is turned towards the Sun, and is therefore illuminated, while the opposite pole (Q) is deprived of sunlight, and remains in constant darkness. The Sun is at his greatest north declination, and is vertical to all places in the northern hemisphere which are 23½° distant from the equator, as at *g*. This hemisphere is wholly illuminated—it is the northern summer. Now in summer, we know that the regions about the north pole have daylight, that the ice then melts, and navigation becomes practicable for a time;—facts which are clearly explained by the Earth then turning her north pole towards the Sun. Again, in our own latitude we have long days and short nights in summer; the day is considerably more than 12 h. in length, and the night proportionally shorter than 12 h. This circumstance is equally a necessary consequence of the Earth's position at A; for in the middle of the temperate zone the night only lasts while the Earth revolves through double the space *b c*, whereas the day will be represented by twice *a b*,—as only one side of the globe can be seen in the engraving. The day is longer than the night nearly in the same proportion that *a b* is longer than *b c*. When the Earth is at A, the Sun is at the commencement of the sign Cancer, or at the *summer solstice*, which occurs about the 21st of June in each year.

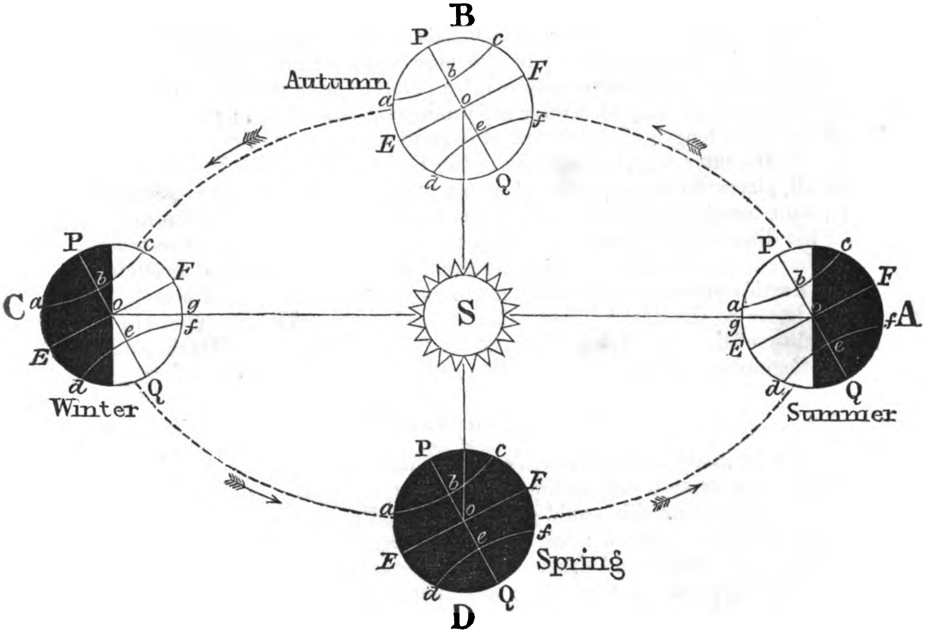

fig. 4.

Next, suppose the Earth to have made half a revolution round the Sun and to have arrived at C; her axis, it will be seen, remains parallel or is always directed to the same point in the heavens. The north pole (P) is now turned away from the Sun and is involved in darkness—it is the arctic night. The south pole, on the contrary, enjoys the greatest possible amount of sunshine. The Sun is vertical to all places 23½° *south* of the equator, as at *g*; he is at his greatest south declination, and the whole of the southern hemisphere is illuminated. This position of the Earth corresponds to the *winter solstice*, which falls about the 21st of December, the Sun being at the beginning of the sign Capricornus. From the short length of *b c* as compared with *a b*, we perceive how the long nights and short days of an English winter are produced: the night at Christmas has attained the length of the day at Midsummer.

At the intermediate positions of the Earth D and B, the Sun is vertical to all places on the equator, as at O: at D he is apparently crossing the equator towards the north, and at B towards the south—our globe moving in the direction of the arrows. It is the *spring equinox* at D, the *autumnal equinox* at B; in both the night is equal in length to the day throughout the Earth's surface.* The former corresponds to the 21st of March, and the latter to the 21st of September in each year. The Sun is at the beginning of the sign Aries, in longitude 0°, on the 21st of March, and at the beginning of Libra, in longitude 180°, on the 23d of September.

PERMANENCY OF THE SEASONS.

The inclination of the Earth's axis to her annual path is subject at present to a very slow diminution, amounting to about one minute in 120 years. Supposing this could go on continually, the equator and ecliptic would at length coincide: instead of the succession of seasons, the inhabitants of the earth would experience a perpetual spring, vegetation could no longer progress as it now does; and though the change must be brought about after an enormous lapse of time, things would eventually be entirely different to what we now find them. But it has been otherwise ordained: before the ecliptic can have approached the equator to a degree sufficient to produce any sensible alteration of climate upon the surface of our globe, its motion in that direction must cease, and after becoming stationary for a time, it will begin to recede towards its present state; its variations being always included within the narrow limit of about 1½°. Spring, summer, autumn, and winter must, therefore, succeed each other through all time; and this astronomical fact recalls to our recollection the promise of the Creator, that as long as the earth remaineth, seed-time and harvest, and cold and heat, and summer and winter, shall not cease. The permanency of the seasons is one of the most beautiful facts which astronomy enables us to explain.

CHANGES IN THE ASPECT OF THE STARRY HEAVENS IN DIFFERENT MONTHS.

In describing the appearances of the stars, it was stated that an observer who examined the heavens in winter, and again in the summer, would find an entire change in the groups of stars or constellations, as they are called, during the intervening months. This is easily explained by the Earth's annual revolution round the Sun.

In fig. 5, suppose A B C D to be the orbit of the Earth, and E F G H the

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* A very small circle round the poles alone excepted.

sphere of the fixed stars, surrounding the Sun in every direction. When our globe is at A, the stars about E are on the meridian at midnight, being evidently seen from the Earth in the opposite quarter to the Sun at S, which is on the meridian at noon: they are most favourably placed for observation. The stars at G, on the contrary, will be invisible, for the Sun intervenes between them and the Earth; they are on the meridian of the spectator about the same time as the Sun, and are always hidden in his rays. In three months the Earth has moved over one-fourth of her orbit and has arrived at B: stars about F now appear on the meridian at midnight, whilst those at E, which previously occupied their places, have descended towards the west and are becoming lost in the sun's refulgence; while those about G are just coming into sight in the east. In three months more the Earth is situated at C, and stars about G shine in the midnight sky; those at F having in their turn vanished in the west. Stars at E are on the meridian at noon, and consequently hidden in daylight; and those about H are just escaping from the Sun's rays, and commencing their appearance in the east. One revolution of the Earth brings the same stars again on the meridian at midnight. Thus it is that the Earth's motion round the Sun as a centre explains the varied aspect of the heavens in the summer and winter skies.

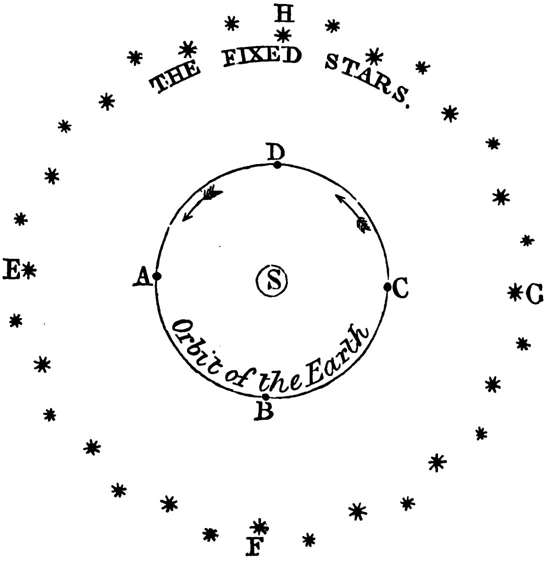

fig. 5.

TRUE FORM OF THE EARTH'S ORBIT. KEPLER'S LAWS.

Hitherto, in speaking of the Earth's orbit and the effect of her annual revolution upon the appearances of the heavens, we have assumed, for the sake of simplicity, that its form was circular: this is not strictly the case.

Kepler, a famous astronomer who lived in the early part of the seventeenth century, was the first to discover the real nature of the tracks pursued by the Earth and other planets in their circuits round the Sun. He was observing with close attention the planet Mars. Sometimes he found its rate of progress was slower than at others; it was at one time behind the place he expected to find it, and at another in advance of it. This occasioned him much perplexity, until at last he detected the true cause of the irregularities, and announced to the world that the paths of the planets are not circles, but ovals or *ellipses,* having the Sun in a certain point called the *focus.* This was the first of three laws of nature discovered by the same philosopher, and universally known as *Kepler's Laws.*

The figure annexed (fig. 6.) is intended to represent the orbit of the Earth; the Sun is situated at S, nearer to one end of the ellipse than to the other. It follows that the Earth's distance from the Sun is not the same during the whole year. It is nearest to the Sun at P, and is then said to be in *perihelion:* it afterwards recedes until it arrives at the point A, which is furthest from the Sun, and is then said to be in *aphelion.* The line joining the perihelion and aphelion is called the *line of apsides.* These terms are not confined in their use to the Earth's orbit, but apply to all the planets.

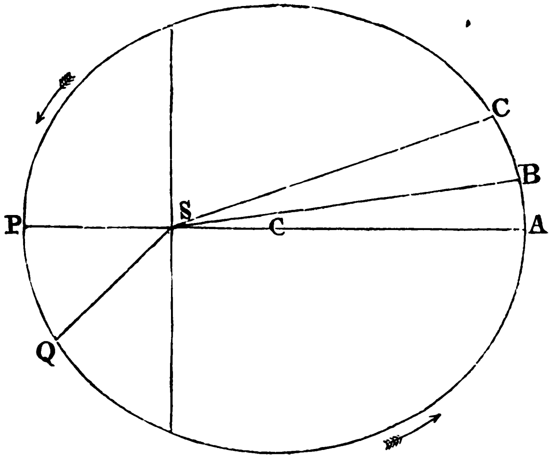

fig. 6.

When the Earth is in perihelion, the Sun is said to be in *perigee,* or nearest the Earth; and when our globe is in aphelion, the Sun is in *apogee,* or furthest from the Earth. The words 'apogee' and 'perigee' are often used by astronomers to indicate the greatest and least distances of any planet from the Earth.

UNEQUAL VELOCITIES OF THE EARTH AND PLANETS IN THEIR ORBITS.

KEPLER'S SECOND LAW.

One consequence of the motion of a heavenly body in an ellipse is a variable rate of progress at different parts of the curve, just as Kepler remarked to take place with the planet Mars. His second law teaches that *equal areas* of the ellipse are always described in *equal times*. To understand what is meant by this, suppose a planet moves in a certain time, a week for instance, from perihelion at P to the point Q; it will have described the area or space included within P S Q P, or by lines drawn from the Sun to its position in the orbit at the beginning and end of the week. Again, suppose the planet to move from aphelion at A to the point B in the same space of time, it will have described the area included within A S B A; and Kepler's law tells us that the spaces P S Q P and A S B A (which are both passed over in one week) must be equal. But the planet at A is so much further from the Sun than at P, that to make the areas equal, it will not require to pass over so large a portion of the ellipse at A as at B; for if we assume it to have advanced from A to C, so that A C shall be equal in length to P Q, it will be evident that the space or area included within A S C A is very much greater than the area P S Q P; A B therefore will be less than P Q; and thus we see how it is that a planet does not always appear to move at the same rate. Its velocity is greatest when it is nearest to the Sun, and least when it is furthest from him.

The line joining the Sun and a planet at any point of its orbit is called the *radius-vector*, which is least at perihelion and greatest at aphelion. It is the true distance of a planet from the Sun. This imaginary line travels round the Sun with the planet; and hence Kepler's second law is often announced thus: *the radius-vector describes equal areas in equal times.*

RELATION BETWEEN THE MEAN DISTANCES AND PERIODS OF THE PLANETS.

KEPLER'S THIRD LAW.

To Kepler we are indebted for the discovery of a striking relation subsisting between the mean distances of the planets and the times in which they complete their revolutions round the Sun. He found that "the squares of the periodic times are to each other in the same proportion as the cubes of the mean distances;" whence it results that, knowing the Earth's period and distance, and the time of revolution of another planet, we can ascertain the distance of that planet expressed in the same way as our own. Thus, if P be the Earth's period, and D her distance from the Sun, and if p and d have the same meaning in the case of another planet, then it follows that

The square of		The square of		The cube of		The cube of
P	:	p	::	D	:	d

A simple proportion, constituting Kepler's third law, which can easily be verified by introducing numbers.

LAW OF UNIVERSAL ATTRACTION.

The learner will naturally inquire, what is it that retains the Earth in her orbit, and causes her to describe year after year, with unerring regularity, the same oval path about the Sun? Kepler, though he discovered the law of motion, was unable to explain it; but our illustrious countryman, Sir Isaac Newton, less than a century after Kepler's day, succeeded in solving this wonderful problem, unfolding to the world the existence of a power in nature which fully accounts for the form and permanency of the planetary orbits. This great man proved that each particle of matter throughout the universe attracts every other particle, with a force proportioned to their distance and the mass or weight of the attracting body, *i. e.* one body attracts another most when nearest to it, and least when furthest removed. This is called the principle of universal gravitation. It is by the action of this force that the planets are retained in their orbits round the Sun, having once received from the Divine Hand the impulse that set them in motion. For, as a planet is attracted towards the Sun, which is by far the largest and most massive body in the system, and is at the same time impelled forward by the motion originally communicated to it, it cannot strictly obey either force, but its actual course is a result of the two combined. Supposing the Sun exercised no influence upon it, having once received the primitive impulse, it would, if undisturbed, move onwards for ever in a straight line. But the attraction of the Sun being in force, the planet's path is bent towards that luminary. It moves onward towards its perihelion, increasing its velocity as the Sun gains more power upon it, through the diminishing distance, until its arrival at that point. The impulse it has received is, however, sufficient to carry it past the perihelion; and it still pursues its course, though with diminishing velocity, till it reaches the aphelion, at which point the rate of motion has so far decreased that the Sun's attraction becomes more powerful, and draws it towards him once more. While the planet is moving from aphelion to perihelion, or approaching the Sun, the influence of that body tends to quicken its rate of motion in the orbit; and while it passes from perihelion to aphelion, his attraction causes a gradual retardation in its speed. The contending forces are so accurately adjusted, that neither can ever gain the ascendency, and the planet must continue to describe its elliptic path through all time.

We cannot pursue this subject further, as, in its details, it is too difficult for an introductory treatise. What has been already said may be rendered more easy of comprehension by a reference to fig. 6.

TRUE DIMENSIONS OF THE EARTH.

We have seen that the Earth is a nearly globular or spherical body, somewhat compressed or flattened at the poles.

The Earth's diameter, in the direction of the equator, is about 7926 miles, but it is 26 miles less in the direction of the poles: the former is termed the equatorial, and the latter the polar diameter.

The circumference of the Earth is about 25,000 miles.

The methods used to find these results will be understood from the following simple case. A person, provided with a suitable measuring instrument, determines the elevation of the pole above the horizon, or his latitude at some one station. He then moves northward, *i. e.* in the line of the meridian, until the pole appears 1° higher than before; and ascertains the distance between the two stations on the earth's surface, which will correspond to 1° of latitude. Now this distance is found to be on an average 69½ English miles; and the whole circumference being divided into 360°, we have only to multiply the number of miles by 360, and we know the distance round the Earth—25,000 miles. But the circumference of every circle is rather more than three times its diameter (3·15), wherefore, by common division, we find the diameter of the globe to be, as above stated, about 7900 English miles. The process here explained is called the measurement of a degree of the meridian.

By performing similar operations in various latitudes, the exact form of the Earth and the amount of flattening at the poles have been determined.

It will afford an idea of the extreme minuteness and accuracy with which these and other astronomical observations are conducted in the present state of science, when we mention that two great mathematicians, who have quite independently worked out the problem, have arrived at numbers, representing the mean diameter of the Earth, which differ only by *fifty-five yards.*

PRECESSION OF THE EQUINOXES.

The equinoxes are not stationary amongst the stars, but possess a retrograde or westerly motion, *i. e.* contrary to the order of the signs, which modern observations shew to be at the rate of about 1° in seventy years, or 50″ of arc annually. This remarkable effect is called the *precession of the equinoxes,* because the position of the equinox in any year precedes, in the order of signs, that which it occupied in the previous one. Precession consequently *increases* the longitudes of the stars at the above rate.

It is the revolution of the pole of the equator round that of the ecliptic, brought about by the action of the Sun, Moon, and other planets, which causes the retrocession of the equinoctial points. This revolution is performed in a path scarcely differing from a circle, at a distance of 23½° between each pole; the time occupied is no less than 25,868 years, in which interval the equinox completes an entire circuit of the heavens.

Suppose Q to be the pole of the ecliptic, and the small circle to be traced out by the pole of the equator in the course of its revolution round Q; also let A B represent a part of the ecliptic, the arrows indicating the order of the signs or the direction of the Sun's apparent motion. When the pole of the equator is at P_1, the equinoctial point will fall at E_1; but when the pole, in its westerly course, arrives at P_2, the equinox will have fallen back from E_1 to E_2; it will have moved contrary to the Sun's apparent motion, so that the point from which we reckon longitudes on the ecliptic, and right ascensions on the equator, must occupy a position amongst the stars when the pole of the equator is at P_2 *behind* that it possessed at the time the pole was at P_1; and as the stars do not really participate in this movement, their longitudes are necessarily increased from year to year.

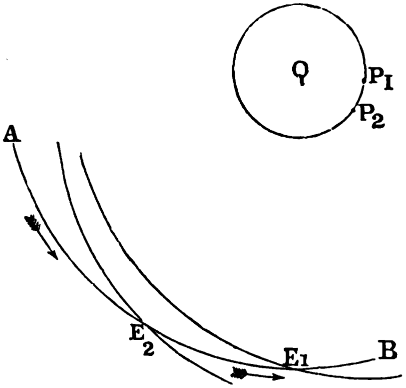

fig. 7.

The precession of the equinoxes was discovered 2000 years ago by

Hipparchus, the most celebrated astronomer of antiquity, who found, on comparing his observations of the longitudes of several stars with others taken about 200 years earlier by Timocharis, that they had increased in the interval more than could be accounted for by any errors in the observations.

Since the time of Hipparchus the equinox has retrograded nearly 30°, or one whole sign. The stars that were then in Aries are now under the sign Pisces; those that were in Taurus have receded into Aries, and so on.

The learner should distinctly understand that the changes in the positions of the heavenly bodies, attributed to the retrograde motion of the equinoctial points, are neither real nor apparent, but merely imaginary or conventional. If, instead of adopting the intersection of the equator and ecliptic as the origin from which to reckon longitudes and right ascensions, a fixed star had been used, there would be no such effect as precession.

NUTATION OF THE EARTH'S AXIS.

The attraction of the Moon upon the spheroidal figure of the Earth gives rise to a slow motion of her axis to and fro, which, from its oscillatory character, has been termed the *nutation*.

Remembering that the pole of the equator is the vanishing-point of the Earth's axis in the heavens, it will be easily comprehended that the effect of nutation must be to impress upon the place of that pole an apparent motion corresponding to the real movement of the Earth's axis; and if there were no other source of disturbance, the result would be that the pole must describe a small ellipse in the heavens every nineteen years or thereabouts, that being the interval in which the moon's attraction goes through all its variations. But the pole of the equator is actually in motion round that of the ecliptic, from a different cause, at the same time that it undergoes the oscillatory motion arising from the nutation of the Earth's axis; whence it appears its true course will be in a wave-like curve, something like that represented in the figure annexed.

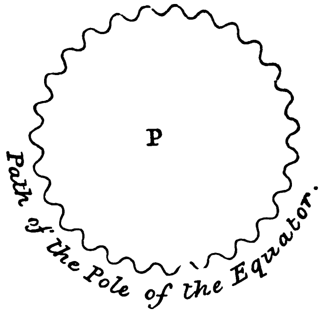

fig. 8.

The effect of nutation is perhaps more readily understood and better exemplified by supposing the mean place of the pole of the equator to describe a circle round the pole of the ecliptic, while its true place revolves about the mean one in a small ellipse, the longer diameter of which is invariably directed towards the latter pole, and is to the shorter one nearly in the proportion of nine to seven.

Every object in the heavens, whether fixed or in motion, is affected to a certain extent by the nutation of the Earth's axis; but the amount of variation from the mean place can be easily calculated for any required moment.

Science is indebted to Dr. Bradley, formerly Astronomer Royal at Greenwich, for his discovery and explanation of this apparent displacement in the situations of the heavenly bodies.

ABERRATION OF LIGHT.

There is another cause whereby the apparent places of the stars differ from their true ones, depending on the progressive motion of light, combined with the motion of the Earth in the ecliptic. The rays emanating from a star appear to reach us from a different direction to what they would do were the Earth at rest.

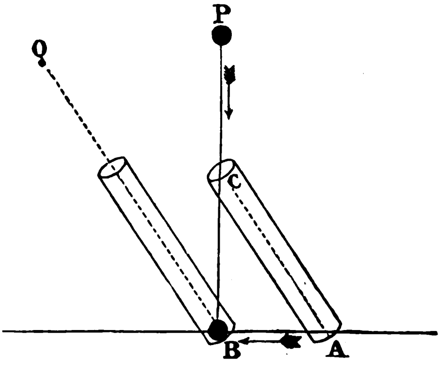

fig. 9.

To illustrate the effect in a general way, we will suppose a ball to be dropped from the point P into the mouth of an inclined tube C A, and that an observer at the bottom of the tube is carried along the horizontal line from A to B, at a velocity *proportioned* to that of the ball in its descent towards the same line: the ball would then travel down the tube without striking against its sides, and when the observer arrives at B, he would see it as if it had come from the point Q, instead of P. If, now, the ball is supposed to represent a ray of light from a star, and A B a part of the ecliptic through which the Earth moves in a certain interval, the nature of the apparent displacement of the star from the cause already mentioned will be readily understood. Its measure is expressed in the figure by the angle P B Q, by which the true place differs from that in which the star seems to be.

This phenomenon is termed *aberration*, and was also discovered and explained by Dr. Bradley in the first half of the eighteenth century.

Another very common illustration of the effect of aberration is the striking of raindrops against the face of a person walking quickly through a shower which is falling vertically; here the raindrops may be taken for the rays of light, and the change of place of the individual for the Earth's motion in her orbit.

When the ray of light is perpendicular to the direction of the Earth's motion, aberration is greatest, and when it is parallel to the same, aberration vanishes altogether. The general effect upon the stars is to cause each one to describe (in appearance only) a small ellipse in the course of a year, the central point being the place the star would occupy if our globe were at rest.

It is necessary to draw a distinction between the kind of aberration which applies to the fixed stars, and what is termed the *aberration of planets and comets*, bodies moving rapidly through space. If the latter were motionless, like the stars, they would be similarly affected by aberration; but when we consider that light requires a certain interval to pass from a planet to the Earth, and that in the meantime the planet itself must have made some progress in its orbit, it is evident that at the moment a ray of light reaches the Earth, the true position of the body from which it proceeded is not in the same direction as that ray, but will differ therefrom by the actual motion of the planet during the transmission of light from it to the Earth. The true position of a moving body at any moment is always in advance of the apparent one. Thus we never see the Sun in the place he really occupies in the ecliptic at the instant of observation, for light requires $8^m\ 18^s$ to travel from that luminary to the Earth, and in this interval the latter has moved at her average velocity over an arc of $20''\cdot5$, or the Sun has apparently changed his place to the same amount; so much therefore will he be observed behind his true point in the ecliptic.

The arc of $20\frac{1}{2}''$, by which the apparent position of the Sun as seen from the Earth, or of the Earth as seen from the Sun, differs on the average from the actual place, is called the *constant of aberration.*

The corrections due to the places of the fixed stars on account of aberration are easily calculable, because we know the relative velocities of light, and of the Earth in her annual orbit, upon which the effect depends. And it is equally easy to determine the corrections required in the observed positions of the planets, because their distances are known to us, and the time that light occupies in travelling from them to the Earth is consequently known also.

THE RECKONING OF TIME.

THE APPARENT SOLAR DAY. THE MEAN SOLAR DAY. EQUATION OF TIME.

From the very earliest ages, when mankind found the necessity of some standard by which to reckon their days and years, the Sun has been universally regarded as the natural regulator of the seasons, and time has been measured by his apparent motion in the heavens. Indeed, that such was to be the use of this magnificent orb to the human race, was declared at the creation; it was to be "for signs and for seasons, and for days and for years."

The interval elapsing between two successive arrivals of the Sun on the meridian of any place is called an *apparent solar day;* and time so reckoned is called *apparent time.* If the sun moved in the *equator* with an equable velocity, days so measured would be of equal length throughout the year; but the Sun's path is in the *ecliptic,* or inclined to the plane of the Earth's diurnal revolution, and his apparent motion is not uniformly the same: for the Earth's elliptic motion, which (as before stated) causes it to move quicker at some times than at others, produces a corresponding variation in the rate of progress of the Sun; and hence the apparent solar day is not of equal length at all times of the year.

To obviate this inconvenience, astronomers suppose a fictitious or imaginary sun to move in the *equator,* with the real sun's average motion in the ecliptic. When this imaginary or *mean sun* comes to the meridian, it is said to be *mean noon,* and when the true sun is in the same position, it is *apparent noon.* Our clocks in common use are regulated to mean time, and will therefore sometimes shew twelve o'clock before the true sun has reached the meridian, while at others they will yet want some minutes to noon when the Sun is so situated. This is what is meant in the almanacs when we read of "Clock before Sun," and "Clock after Sun."

The *difference* between mean and apparent time is called the *equation of time*, and is the quantity we should have to apply to the time by clock of the true Sun's arrival on the meridian, or of apparent noon, in order to obtain mean noon. Four times in every year the equation of time is *zero*, or the true and imaginary suns coincide. Twice in the same period the clock is *before* the Sun, and twice *after* it. The equation is set down in the almanacs, and is indispensably necessary for regulating a clock by the Sun.

The interval elapsing between two successive passages of the imaginary or mean sun over the meridian of a place is termed a *mean solar day*, and this is the day in common use amongst all civilised nations.

An exact knowledge of the time is of the highest importance in navigation. The sailor requires to know before his departure on a long voyage, not only to what extent his watch may be fast or slow upon the cor-

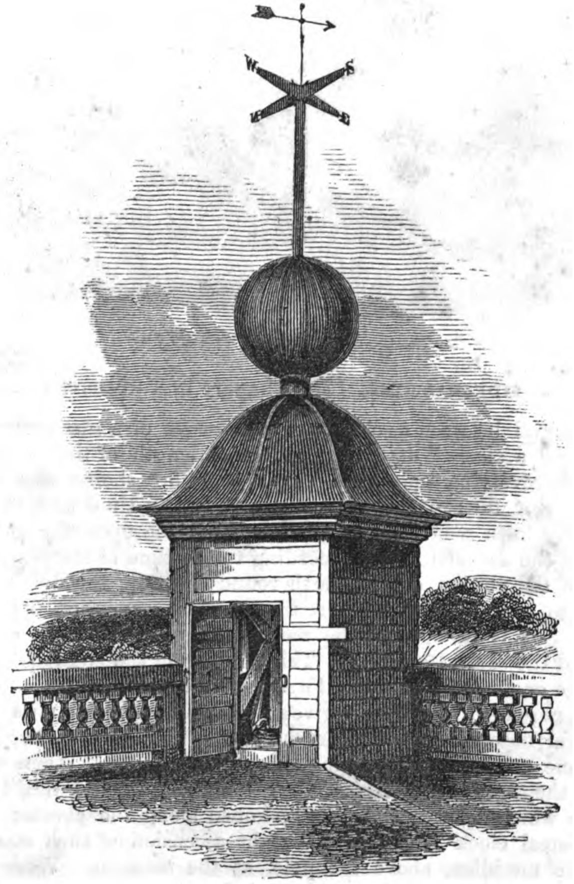

fig. 10. The Time-ball at Greenwich.

rect time, but also how much it loses or gains thereon in the course of a day, that he may be able to calculate its error when at sea. To afford him an opportunity of doing this, arrangements have been made at several of our principal seaports to shew the exact moment of 1 o'clock every day by the dropping of a ball from the top of a mast to which it is attached, in some open situation. At the Royal Observatory, Greenwich, a time-ball was erected many years ago for the convenience of the numerous vessels on the river Thames: it falls at 1 o'clock daily, the precise instant being shewn by the ball *leaving* the top of the mast. When observations of the heavenly bodies can be pretty regularly taken, the error in letting off the Greenwich time-ball is less than two-tenths of a second.

fig. 11. The Royal Observatory, Greenwich.

SIDEREAL TIME. THE TRANSIT INSTRUMENT.

The interval between two successive passages of a *star* over the meridian is called a *sidereal* day. It is the true length of time occupied by the Earth in revolving upon its axis, and is $3^m\ 56^s$ shorter than the mean solar day, *i.e.* a star returns to the meridian in less time than the Sun by $3^m\ 56^s$. We have seen that the same star may be upon the meridian at all hours of the day and night, according to the time of the year, and this arises from the motion of the Earth round the Sun, through which our globe has to complete rather more than a whole revolution upon its axis before the Sun is brought to the meridian again, whereas a star would have passed the same 4^m earlier. This gaining of the stars upon the Sun is called the *acceleration of sidereal upon mean time.*

Clocks regulated by the stars give sidereal time, and are always used in astronomical observatories: one revolution of the clock through 24^h represents one apparent revolution of the starry sphere. When the clock shews 0^h, the *first point of Aries* is on the meridian, and this being the point from which right ascension is reckoned along the equator, the time by the sidereal clock is always the right ascension of such stars as are passing the meridian, above the pole, at the moment. Wherefore, by noting the time when an unknown star is in this position, we have its distance from the first point of Aries at once. Telescopes for this purpose are fixed in the meridian at all observatories, and are called Transit-instruments. Wires are placed within the tube of the telescope, so that they may be seen at the same time as the star, which the astronomer watches as it is carried across the telescope by the diurnal revolution of the Earth; he notes by the clock the moment when it passes the wires, and thus determines the precise time of its meridian transit, which gives him the right ascension of the star.

THE CIVIL DAY.

Astronomers commence the day at mean noon, counting on through 24^h to the next mean noon. Their day is 12^h behind the civil day in general use, which is supposed to begin at the midnight preceding, and is divided into two intervals of 12^h each, distinguished as *ante meridiem* or A.M., and *post meridiem* or P.M. Thus, 4 o'clock A.M. of October 15^d civil time, is the same as October 14^d 16^h astronomical time. From noon to midnight the civil hour agrees with the astronomical.

In its general acceptation the word *day* is applied to the space of time during which the Sun is above the horizon of a place, while *night* is the remainder of the 24^h. Some nations still reckon their time by the rising and setting of the Sun, and the custom was almost universal in former ages; the third hour of the day was then the third hour after sun-rise, and the fourth hour of the night was the fourth hour after sun-setting.

LENGTH OF THE YEAR. THE SIDEREAL AND TROPICAL YEARS.

The Earth's revolution round the Sun, or, which amounts to the same thing, the apparent revolution of the Sun in the ecliptic, marks the length of the year.

The interval of time elapsing from the moment when the Sun leaves a fixed star until his return to it again, is called a *sidereal* year, and consists of 365^d 6^h 9^m 11^s mean solar time. This is the length of time occupied by the Earth in performing one complete revolution about the Sun.

The *tropical*, or mean solar year, is the time intervening between two successive passages of the Sun through the same equinox or tropic. These points recede upon the ecliptic from east to west, and the apparent motion of the Sun is from west to east; so that he must necessarily complete a whole revolution, with respect to the equinox or tropic, in less time than he would return to the same fixed star, because these points in the course of the year have gone back to a certain extent to meet him. Hence the tropical year is shorter than the sidereal year, and differs therefrom by the time the Sun requires to describe a space of 50 seconds in longitude, which is the amount of the annual precession of the equinox. It is found to consist of 365^d 5^h 48^m 48^s mean solar time.

The tropical year diminishes in length at the present rate of about six-tenths of a second in a century; it is consequently shorter now than in the time of Hipparchus by about twelve seconds.

THE JULIAN AND GREGORIAN STYLES.

The tropical or mean solar year does not consist of a *whole* number of mean solar days; on the contrary, we have just seen that there are 365 such days and 5^h 42^m 48^s over; or expressing the length of the year in days and decimal fractions, it will be 365·24225 days. A hundred years of 365 days each (making 36,500) would therefore be more than 24 days in defect of 365 revolutions of the Sun with respect to the equinox. To set this right, it was decreed by Julius Cæsar, at the instance or with the previous aid of Sosigenes, an astronomer, that one day should be intercalated or added every fourth year, making 25 days extra in the century.

The fourth year, consisting of 366 days, was called *bissextile* or leap-year, the day added being assigned to the month of February. A century so reckoned contains 36,525 days, viz. 75 common years and 25 leap-years; but that number of days still differs from the actual length of time occupied by 100 tropical revolutions of the Sun, and although its deviation therefrom is less than one day in a single century, after a much longer lapse of time it becomes of course greater in magnitude and importance.

In the sixteenth century, about ten days having been gained on the Julian mode of reckoning, another alteration was made by Pope Gregory XVI. in 1582, which has been adopted by every civilised country in the world, Russia alone excepted. The improvement, for such it is, consists in making those only of the secular years leap-years which are divisible by four without a remainder; thus 1600 has 366 days, or is a bissextile year, while 1700, 1800, and 1900 have only 365 days, or are common years. This is called the *Gregorian* or *New Style*, to distinguish it from the former, which is termed the *Julian* or *Old Style;* its adoption leaves an outstanding error of less than 1 day in 3000 years.

Were it not for such an adjustment of our calendar with the duration of the Sun's tropical revolution in the ecliptic, the seasons would not occur, as they do now, in the same months. In one year we should have winter in December, and after a lapse of time in June. The Gregorian correction removes the occurrence of such a change in the aspect of the months to a very distant period.

DISTANCE OF THE EARTH FROM THE SUN. PROGRESSIVE MOTION OF THE LINE OF APSIDES.

Accurate observations, upon a method which will shortly be explained, have proved that the average or mean distance between the Earth and the Sun exceeds 95,000,000 (ninety-five millions) of miles.*

It is of the highest importance in astronomy that this number should be exactly known, because it is used in calculations as a scale by which to estimate planetary distances; and if we have not the accurate distance of our own globe from the Sun, we cannot find that of any other planet with precision.

We have seen that the Earth's distance from the Sun is not the same at all times of the year; the fact is, she is nearer to that luminary at Christmas than at midsummer by 3,200,000 miles; for (see fig. 6) the point P, where the Sun is in perigee, corresponds at present to the 10th degree of the sign Cancer, or 100° of longitude, which the Earth occupies about December 31; and the point A, where the Sun is in apogee, is consequently in the 10th degree of the opposite sign Capricornus, or 280° of longitude, which is the Earth's position at the beginning of July. We do not perceive any increase of heat in these latitudes from the greater proximity

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* More accurately, 95,370,000.

of the Sun at Christmas, because the north pole is then turned *from* him, and his rays therefore fall very obliquely on the north temperate zone.

Yet the Sun has not always been nearest to the Earth at Christmas. The line joining the perihelion and aphelion in the Earth's orbit, which is the longest diameter of her ellipse, and is termed the *line of apsides,* does not retain one constant direction, but slowly shifts its position along the ecliptic in the order of the signs. Its motion, however, is so slow, that since the creation it has travelled over little more than a fourth part of its journey, and will require 21,000 years to complete a whole revolution in the ecliptic. About the middle of the thirteenth century the Sun's perigee exactly coincided with the winter solstice. In A.D. 6485 it will correspond to the vernal equinox, and the Earth will then be nearest to the Sun in March.

The progressive motion of the line of apsides causes a slight change in the *length* of the seasons in successive ages.

THE MOON.

HER REVOLUTION ROUND THE EARTH.

The Moon is one of the secondary planets or satellites, and revolves about her primary the Earth, while the latter is travelling round the Sun. Her apparent course amongst the stars is from west to east, like that of the Sun.

A complete revolution of the Moon about the Earth occupies $27^d\ 7^h\ 43^m$, which is the time intervening between her departure from a fixed star and her return to it again: this is called the *sidereal* revolution.

The Moon requires a longer interval to go through a revolution with respect to the Sun, because his apparent place in the heavens advances considerably in the space of $27^d\ 7^h\ 43^m$, and she has so much further to travel before overtaking him.

When the Moon has the same longitude as the Sun, and is consequently *between* that body and the Earth, she is said to be in *conjunction* with the Sun; and when she appears in the opposite part of the heavens, having the Earth between her and the Sun, she is in *opposition* to him. The terms conjunction and opposition are used by astronomers in relation to other heavenly bodies besides the Sun and Moon. At either of the two points at equal distances from conjunction and opposition, and therefore differing 90° or one-fourth of circumference, the Moon is said to be in *quadrature.*

The interval between two conjunctions in which the Moon completes her revolution with respect to the Sun, is called her *synodical* period, and is found to consist of $29^d\ 12^h\ 44^m$.

The path described by the Moon about the Earth is not situate in the plane of the ecliptic, but is inclined thereto rather more than 5°.

DISTANCE OF THE MOON FROM THE EARTH. HER TRUE DIAMETER.

The Moon is by far the nearest to us of all the heavenly bodies, her average distance not exceeding 239,000 miles; but owing to the elliptic form of her orbit she is sometimes 13,000 miles nearer than this in perigee, or further, in apogee.

The distance from the Earth to the Moon is therefore 400 *times less* than that separating our globe from the Sun.

The Moon is much less in magnitude than the Earth, her diameter being only 2160 miles. It would require *fifty* globes of the size of the Moon to make one as large in bulk as the Earth.

PHASES OF THE MOON.

By the *phases* of the Moon are understood the various figures which her illuminated portion assumes in the course of her journey round the Earth.

The Moon is globular or spherical in form, and, like every other planet, primary and secondary, derives her light from the Sun.

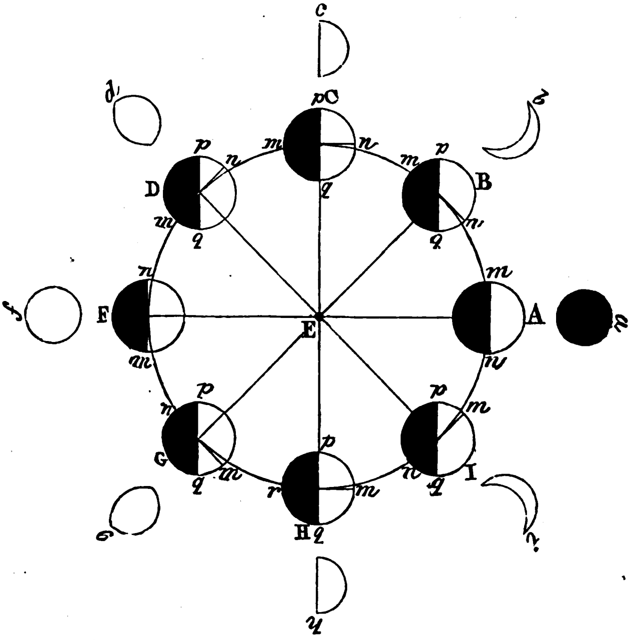

fig. 12.

To explain the succession of phases presented by our satellite, suppose, in fig. 12, A C F H to represent the orbit of the Moon about the Earth at E, the Sun being situate at S; only one half of her surface can receive the Sun's light at the same time. The line *m n*, which is perpendicular to one joining the centres of the Earth and Moon in each position of the latter (at A, B, C, D, &c.), defines the hemisphere which is visible to the inhabitants of the Earth. Now, if the moon is at A, between the Sun and our globe, the whole of her enlightened hemisphere is turned away from us, its limit corresponds with *m n*, and the Moon is invisible, except on certain rare occasions, to which we shall presently refer. She is now in conjunction with the Sun, and it is said to be *new* moon: another journey round the Earth is just commencing.

Next, suppose her to have advanced to B, where she is seen in the evening sky after sunset, a short distance from the west horizon, (her apparent motion in the heavens being from west to east,) here *p q* divides the illuminated half of the Moon from the dark hemisphere, while *m n*, as before, is the limit of her *visible* surface; but in this position, part of the enlightened hemisphere from *q* to *n* is *within* the visible portion, and she assumes the appearance given at *b*.

Continuing her eastward progress round the Earth, the Moon reaches the point C, when the lines *p q* and *m n* are perpendicular to each other: the visible portion limited by *m n* is now half light and half dark; our satellite has consequently the form of a half-moon as represented at *c*. Her angular distance from the Sun, called by astronomers her *elongation*, is here equal to one-fourth of the circumference, or 90°; she is in quadrature and at the *first quarter*.

On arriving at D, a further extent of the illuminated surface will have come into view, the only dark part in the visible half lying between *m* and *q*, while a much greater breadth of surface, from *q* to *n*, is in sunlight. The enlightened part is therefore greater than a half circle, and when this is the case, the moon is said to be *gibbous*, as at *d*.

Next, we will suppose our satellite to have arrived at F, where she passes the meridian at midnight, for we then see her in the opposite part of the heavens to that which the Sun occupies, in other words, she is in *opposition* to the Sun: the lines *m n* and *p q* again coincide, so that the visible and illuminated hemispheres exactly correspond, and we have a wholly enlightened or *full* moon, as at *f*. She has now completed half a revolution round the Earth, and in the meantime presented every variety of form, from the slender crescent as she receded from A, to the perfect circle at F.

During the last half-revolution, while travelling from F through H to A, the same phases will be retraced. At *g* the Moon is again *gibbous*, at H a half-moon and in her *last quarter* or quadrature, being 90° from the Sun towards the west, and at I assumes once more the crescent shape in the morning heavens. But it is necessary to observe, that as the illuminated side is always that which is turned towards the Sun, we now have the dark part on the west side, whereas before it was towards the east. Between I and A the crescent becomes less and less until it is lost altogether near the eastern horizon, shortly before sunrise.

From what has been said above, the learner will easily discover that the phases of the Moon recur in the same order, in the space of a *synodical* revolution occupying $29^d\ 12^h\ 44^m$, which we have already defined to be the interval elapsing from the moment when the Moon leaves the Sun, until her next return to him.

The term *gibbous* is one applied generally to the figure of a heavenly body when its visible surface is less than a circle but greater than a semicircle.

ECLIPSES OF THE SUN AND MOON.

We have before remarked that the orbit of the Moon does not lie exactly in the same plane or level as the Earth's, but is inclined thereto at an angle of rather more than 5°. The two points where her path intersects the ecliptic are called the *nodes*, and the line joining these points is termed the *line of nodes*. When the Moon crosses the ecliptic passing from the south to the north side, she is in her *ascending* node: the opposite point of longitude, where she crosses it from north to south is called the *descending* node.

Although to a casual observer there is scarcely any appreciable difference between the apparent sizes of the Sun and Moon, yet as all objects seem larger the nearer they are to us, the varying distances of these luminaries must clearly give rise to some change in their diameters, though it may be too small to be easily detected without suitable measuring instruments. Such is found to be the case: the Sun's diameter alters slightly during the course of the year, according to the position of the Earth in her elliptical orbit; while the Moon's varies more rapidly in her monthly revolution about our globe. It thus happens that when the Moon is in perigee, her diameter exceeds that of the Sun, and falls short of it when she is in apogee.

Now, if the Moon should pass through either node at or near the time of conjunction, or *new moon*, she must necessarily come between the Earth and the Sun, for the three bodies will be in the same straight line. To certain parts of the earth the Sun may be wholly or partially hidden by the intervention of the Moon, according to the apparent diameters of the two luminaries at the time, and their exact coincidence or otherwise: hence arises an *eclipse of the Sun*.

The Earth and Moon, being opaque bodies illuminated by the Sun, must both *cast a shadow* into space. The Earth's shadow extends far beyond the orbit of our satellite. The Moon's is much less: in perigee it extends as far as her distance from the Earth, but in apogee falls something short of it.

If the Moon, at or near the time of opposition, or *full moon*, should pass through either node, she will be, as before, in the same line as the Earth and Sun, and, in the present case, involved in the *shadow of the Earth*. An *eclipse of the Moon* will take place, the Sun's light being cut off by the interposition of our globe.

Eclipses, whether of the Sun or Moon, can only occur near the nodes, because at all other times the distance of the Moon from the ecliptic (or her latitude) causes her to pass above or below the Sun at conjunction, and north or south of the earth's shadow at opposition. Wherefore, notwithstanding the Moon must cross the ecliptic at the node about twenty-five times in every year, it will commonly happen that she is not, on these occasions, in the same line as the Earth and Sun, and consequently eclipses are of less frequent occurrence. There can never happen *more than seven* eclipses in the course of a year, nor *fewer than two*.

An eclipse of the Sun can take place only at new Moon, and a lunar eclipse only at the time of full Moon.

TOTAL, ANNULAR, AND PARTIAL ECLIPSES OF THE SUN.

We proceed to explain more particularly, with the aid of fig. 13, the nature of a solar eclipse.

Suppose S to be the position of the Sun, E the Earth, and M the Moon at conjunction, and therefore between the Earth and Sun. We will first consider the case when the Moon is in perigee, or at her least distance from our globe. Her dark shadow falls upon its surface at *a b*, and within that space the Sun will be entirely obscured from the inhabitants by the dark body of the Moon: a *total* eclipse of the Sun takes place. The breadth of this space (*ab*) is never very large, averaging from 130 to 160 English miles only. The points *a* and *b*, when lines drawn through the borders or *limbs* of the Sun and Moon (as astronomers term them) fall upon the Earth, are the northern and southern limits of the total eclipse. From *a* to *c* on one side, and from *b* to *d* on the other side of the dark shadow, a part only of the Sun's disc will be covered by the opaque body of the Moon, and within these spaces a *partial* eclipse takes place, *c* and *d* marking its north and south limits respectively; for at *c*, the south limb of the Sun *h* will be just in contact with the northernmost point of the Moon at *i*; and similarly at *d*, the north limb of the Sun *g* will appear to touch the south edge of the Moon at *k*. At *c* the Moon passes *below* the Sun's disc, and at *d above* it. Beyond these points, from *c* to *e*, and from *d* to *f*, no eclipse can happen, nor, it is plain, can any part of the phenomenon be seen by the inhabitants of that side of the Earth turned away from the Sun, and which have consequently night, as shewn in the shaded part of the figure at E.

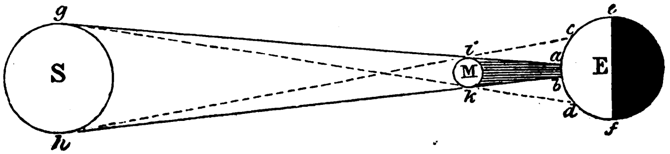

fig. 13.

Next, we will suppose the Moon, at the time of conjunction, to be in apogee, or furthest from the Earth; in this case her apparent diameter is less than the Sun's, and the dark shadow falls short of the Earth, as at *l* (fig. 14). Under these circumstances a *total* eclipse cannot occur. Midway between the points *a* and *b*, where the sides of the shadow extended meet the Earth's surface, a portion of the Sun's disc near its borders, from *g* to *m* and from *h* to *n*, will remain unobscured, while the central parts are covered by the Moon. The visible part of the Sun has then the form of a ring or *annulus*, and hence this appearance is termed an *annular* eclipse. The whole of the Moon's opaque body is seen projected as it were upon the Sun's disc (fig. 15). At the point *a*, which is the northern limit of the *annular phase* on the Earth, the south limb of the Moon at *k* will appear to come in contact with the Sun's south limb at *h*, and the

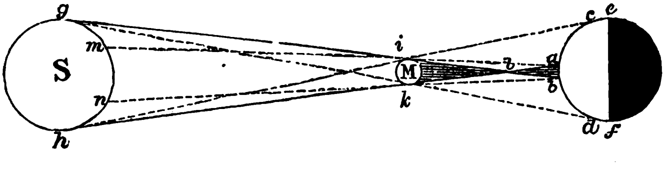

fig. 14.

eclipse will have the appearance given in fig. 16. At *b*, the southern limit of the same phase, the northern limbs of the Sun and Moon will coincide, and the eclipse will be seen as in fig. 17. From *a* to *c* and from *b* to *d*, a *partial* eclipse will be visible, less and less of the Sun's disc being covered by the Moon as we recede from *a* and *b*, until at *c*, the south limb of the Sun *h* is in contact with the north limb of the Moon at *i*; and similarly at *d*, the north limb of the Sun *g* corresponds with the opposite one of the moon *k*. Beyond *c* and *d* no eclipse takes place. These points are determined by lines drawn from *h* through *i*, and from *m* through *k*, to meet the surface of the Earth; while the north and south limits of *annular* phase, at *a* and *b*, are defined by lines drawn from *h* through *k* and from *m* through *i*, to the Earth's surface as before. The inhabitants of the shaded hemisphere, on the right of *ef*, do not have the Sun above their horizon during the eclipse, which therefore takes place while it is night in those parts of the globe.

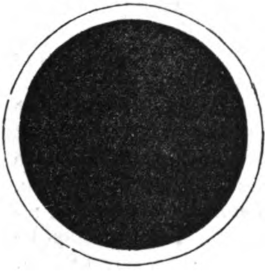

fig. 15. Central and Annular Eclipse.

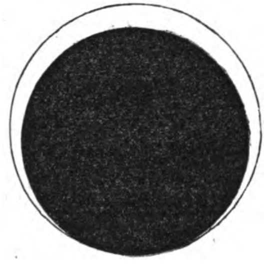

fig. 16. Annular Eclipse. Northern Limit.

fig. 17. Annular Eclipse Southern Limit.

A total or annular eclipse of the Sun is of very rare occurrence at any particular place. The belt of the Earth's surface covered by the shadow in a total eclipse seldom exceeds 2° in breadth, or about 140 English miles, and consequently it will seldom happen that the same place is included within the tracks of any two eclipses following each other at a short interval. In London, for instance, there has been no total eclipse since the year 1715, and more than five and a half centuries had then elapsed since the previous one. The last annular eclipse visible in this country occurred in October 1847.

The longest possible duration of a total solar eclipse extends only to seven minutes, and of an annular one to about nine minutes.

A total eclipse of the Sun is one of the most terrible phenomena that man can witness: the unnatural appearance of the earth and heavens during its continuance are such as to impress the mind with the deepest awe, and have produced great terror amongst the ignorant in all ages. Around the Sun himself a beautiful circle of light called a *corona* is visible, while the Moon passes before him, and prominences, or flames, as they are often termed, of a bright rose-red colour, make their appearance at different points round the border of the dark moon. The corona is believed to be an atmosphere of the Sun, rendered visible by the intervention of our satellite; the red projections are also known to be in some way connected with the physical constitution of the solar globe, though at present their precise nature is not understood. In the total eclipse of July 1851, a very remarkable red "flame" was observed; it was shaped like a Turkish scimitar, strongly coloured with rose-red at the borders, but paler in the centre.

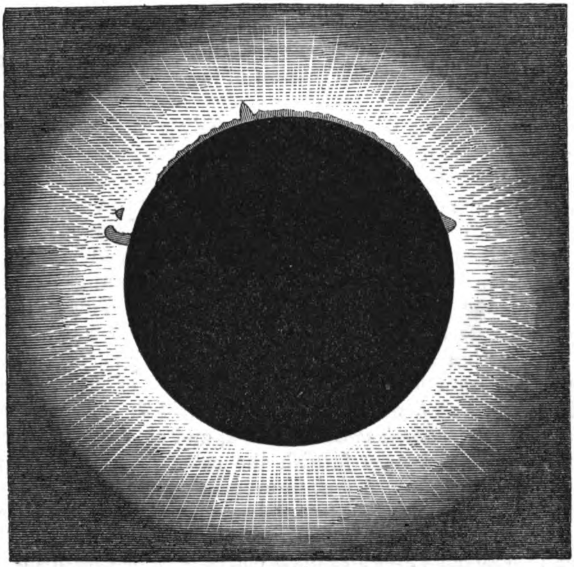

fig. 18.

ECLIPSES OF THE MOON.

In fig. 19, S represents the Sun, E the Earth, and *a, b, c, d,* different positions of the Moon in her orbit, about the time of her opposition. The Earth is now between the Sun and Moon, and will therefore throw her shadow in the direction of the latter body. Now if we draw lines through the upper and lower edges of the Sun on the figure at *g* and *h*, passing respectively through *e* and *f*, the upper and lower points on the earth, and continue these lines to *k*, the space covered by the dark shadow of our globe will be that included within the lines *e k* and *f k*, as shewn in the

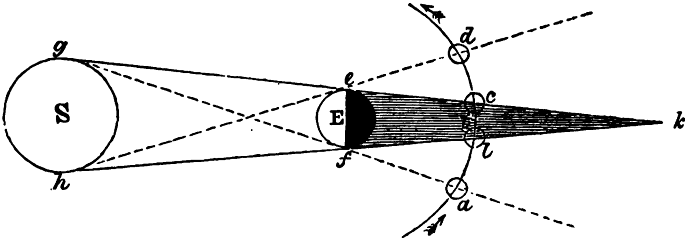

fig. 19.

darkly-shaded part of the engraving: the form of the shadow is that of a *cone*.

Again, if we draw other lines *h e d* and *g f a* from the Sun's upper and lower points touching the *opposite* sides of the Earth and continued to the Moon's orbit, we have two other spaces within which a *portion* only of the Sun's rays are cut off by the intervention of the Earth and a fainter shadow thereby produced.

A lunar eclipse begins when the Moon arrives at the point *a;* she then enters the lighter shadow, called by astronomers the *penumbra,** and at this moment her *first contact with the penumbra* takes place. At *b* she encounters the dark shadow of the Earth, frequently termed the *umbra,* and at this point we have the *first contact with the dark shadow.* If the Moon's course lies nearly through the *centre* of the umbra, she will be totally eclipsed while moving from *b* to *c,* for within that space no sunlight can reach her surface owing to the interference of the Earth; but if, on the other hand, her path be so far north or south of it as to cause only a part of her globe to be included within the conical shadow, she will be *partially* eclipsed while journeying from *b* to *c,* the greatest degree of obscuration taking place on her arrival at *i,* which point is the *middle* of the eclipse. At *c* the *last contact with the dark shadow* occurs, and at *d* the *last contact with the penumbra.* The almanacs furnish the calculated moments when the moon arrives at the points *a, b, c, d,* in every eclipse.

Whether a lunar eclipse will be total or partial depends upon the distance of our satellite from her node at the time of full moon, when she is at the point *i.* For the Earth's shadow where it is traversed by the Moon does not extend more than 1⅓ lunar diameters above and below the plane of the ecliptic; whereas the Moon, except she be very near her node, may pass considerably further north or south of the ecliptic, and only a portion of her disc be included within the Earth's shadow.

An eclipse of the Moon, whether total or partial, is visible to the whole of that hemisphere of the Earth which is turned towards the luminary at the time; hence it is seen over a far greater extent of surface than an eclipse of the Sun. In those parts where it is about midnight at the middle of the eclipse, the Moon will be near the meridian, and other places where the night is just beginning or ending, will have her nearer the east or west horizon respectively. So it will happen that while the inhabitants of some districts witness the eclipse throughout its continuance, those of other regions on the earth will see merely its beginning, and others again only the termination.

The Moon may remain within the Earth's dark shadow, or in other words, a *total* eclipse may last more than 1¾ hours, and the interval between the first entrance into the penumbra, and final departure from it may extend to 5½ hours.

In most eclipses our satellite does not disappear even when deeply immersed in the Earth's shadow, but may still be seen in the telescope and often with the naked eye, of a deep red or coppery colour. Sometimes, however, it has been recorded that no trace of her remained; she has en-

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* From two Latin words—pene, *almost,* and umbra, *a shadow.* The phrases, "first contact with penumbra," &c., printed in italics, are met with in the common almanacs; and hence it is desirable the learner should fully understand their meaning.

tirely vanished after entering the dark shadow. These varying conditions are accounted for by the different states of the earth's atmosphere.

PERIODICAL RECURRENCE OF ECLIPSES. ANCIENT ECLIPSES AND THEIR USE IN CHRONOLOGY.

The nodes of the Moon's orbit, which we have before explained to be the two points where it crosses the Earth's path, are not stationary, but move backward or contrary to the order of the signs at the rate of about 19° annually, completing a revolution round the ecliptic in $18^y\,219^d$ nearly. The Moon performs a revolution with respect to the node in $27^d\ 5^h\ 6^m$, that is, the interval between two successive passages of the luminary through the same node amounts to this period: it is termed a *synodical revolution of the node*, and must be carefully distinguished from the *synodical revolution of the Moon*, which is quite another thing. It is shorter than the latter, because the backward motion of the node upon the ecliptic brings the Moon into contact with it before she comes again into conjunction or opposition. It has been shewn already how the occurrence of eclipses depends upon the position of the Moon with respect to her nodes; it now remains to point out one remarkable effect of their gradual retrocession upon the ecliptic.

The Moon advances from one conjunction or opposition to another in $29^d\ 12^h\ 44^m$—her synodical period: 223 such periods will amount to 6585⅓ days. But nineteen synodical revolutions of the node are completed in 6585¾ days, which nearly agrees with the 223 synodical periods of the Moon. It is not very difficult to see the result of this close approximation. 6585 days after one conjunction or opposition, the Moon will again be at the same point, and the line of nodes will be so nearly in the same position, that if an eclipse took place at either conjunction or opposition, it must *occur again*, and under similar, though not precisely the same, conditions. Thus it happens, that eclipses do occur every 6585 days in very nearly the same order as before. The ancient Greek astronomers were fully aware of this circumstance, and distinguished the period under the name *Saros*.

Eclipses naturally attracted the attention of mankind at a very remote period; there are now extant observations of three eclipses of the moon, observed by the Chaldeans 720 years before the Christian era, or more than 2500 years ago; they are recorded by the Egyptian astronomer Claudius Ptolemy, and occurred in the reign of Mardokempadius, king of Babylon, not long after the foundation of Rome, and about the epoch when Isaiah is supposed to have prophesied. These and other ancient eclipses of the Moon, of which we have the particulars, have rendered eminent service to astronomers in studying the laws that regulate her motion.

The earliest eclipse of the Sun on record is one said to have been predicted by Thales, the celebrated philosopher, and now believed to have taken place on the 28th of May, 585 years before Christ. The armies of Media and Lydia were at the time engaged in combat; but the astonishment and awe produced by the absence of the sun's light were so great, that both sides threw down their arms and concluded a peace upon the spot. The date of this singular occurrence has been much discussed, but astronomy points to that we have just given as the most probable.

Eclipses are of great importance in chronology; for if any memorable event be connected with the mention of one of these phenomena, it may be, and often is, possible to recover the true date. The siege of the ancient city Larissa, supposed to have occupied the site of Nineveh, was interrupted by an eclipse of the sun; another is stated to have taken place when Agathocles, with his fleet, was passing from Syracuse into Africa to carry on the war against the Carthaginians; and there are many similar cases. The eclipse of Agathocles has been satisfactorily identified with the one which happened in August, A.C. 310.

THE TIDES.

The alternate rise and fall of the waters of the ocean, which we call the *tides*, is chiefly caused by the attraction of the Moon, whereby the sea is raised above its ordinary level at those parts of the Earth's surface immediately beneath her, and proportionally depressed at others. The Sun likewise exercises a similar attraction; but owing to the Moon's distance from the Earth being four hundred times less than that of the Sun, her influence is very far the greatest.

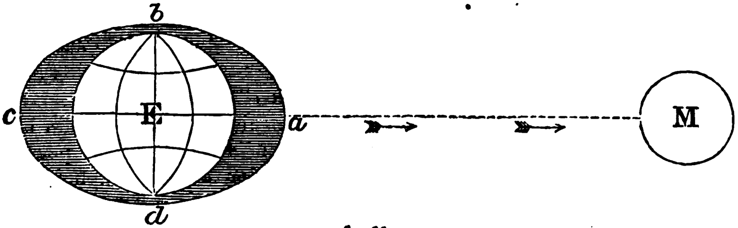

fig. 20.

In fig. 20 the Moon is supposed to be at M; her attraction raises the waters on the surface of the Earth E, at those parts which are turned towards her, as at *a*, drawing them away from *b* and *d*; it is *high water* at *a*, and *low water* at *b* and *d*. But, singular as it may appear at first sight, the influence of the Moon produces high water simultaneously at opposite parts of the earth, viz. at *a* and *c*. To understand how this is, it must be borne in mind that the attraction of a heavenly body diminishes as its distance increases, so that the waters at *a*, in those parts of the earth nearest to the Moon, are more powerfully affected than the central parts of the earth at E; and similarly, these central parts will be more strongly attracted than the waters on that side of the earth opposite to the Moon, as at *c*. The result is, that while high water is produced at *a* by the direct attraction of the Moon, situate at M, high water is also caused on the opposite side by the earth itself being drawn away towards the Moon, more than the ocean at *c*, the waters in this case being *left behind*, so to speak, to the amount of the tide. To distinguish the two, the tide at *a* is called the *superior*, and that at *c* the *inferior* tide.

These remarks will apply equally well if we suppose M to be the Sun; but the attraction of this luminary being less felt than that of the Moon, the waters are not so much disturbed, or the *solar* tide falls far short of the *lunar* one in elevation.

The influence of the Moon upon the waters of the ocean is not *instantaneous*, but requires a certain time to produce its greatest effect; hence it happens that high water occurs, not when the Moon is exactly on the meridian of a place, at which instant it is nearest to it, but some hours later: high water, or the tide, is, in other words, caused by a great wave raised by the Moon's attraction, and *following her* in her apparent progress round the Earth.

When the Sun and Moon act upon the seas in the same direction, the tides are highest, and when the luminaries are 90° apart, or differ about 6^h in the time of passing the meridian of a place, the tides are least, because the Sun's attraction is then exercised *against* that of the Moon. The highest tides, therefore, occur after new and full moon, and are termed *spring* tides; and the lowest, after the quadratures or first and last quarters, and are called *neap* tides.

Figs. 21 and 22 will serve to impress upon the memory the cause of the variable height of the tide in different relative positions of the Sun and Moon. In fig. 21 the Moon is in conjunction with the Sun; both bodies attract in the same direction: the *solar* tide is consequently added to the *lunar* one, and the two united produce the greatest possible disturbance upon the waters of the ocean, raising them up to their high estpoint at *a* and *c*, and diminishing them as far as possible at *b* and *d*. The same effect follows if the Moon is in *opposition;* in either case we have spring tides.

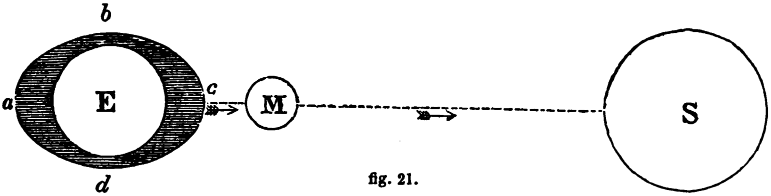

fig. 21.

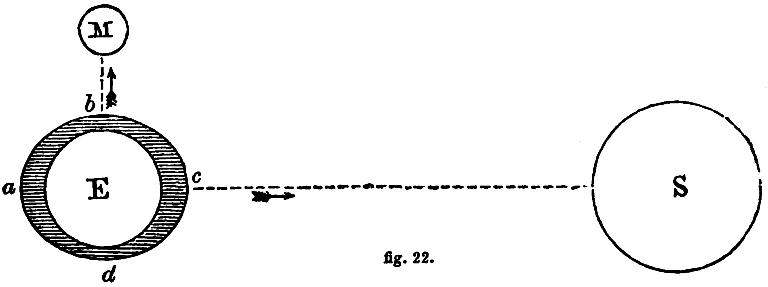

fig. 22.

But if the Moon be in quadrature, as at M fig. 22, her attraction raises the water at *a*, *c*, and diminishes them at *b* and *d*, while the Sun, on the contrary, raises them at *b* and *d*, but draws them away from *a* and *c;* the Moon's action being strongest, it is still high water at *a* and *c*, but the tide at these points is the result of the Moon's influence, diminished by that of the Sun. The difference between the high and low water is less than in the former case, and we have a *neap* tide.

In the interval between two successive passages of the Moon over the meridian of a place, called a *lunar day*, it is twice high water and twice low water. The lunar day averages 24^h 50^m; it is necessarily longer than the sidereal day, owing to the motion of the Moon in her orbit, through which the Earth's meridian has to travel round some distance (about 13°), over a complete revolution in reference to the stars, before our satellite is again overtaken.

In the lapse of about 24^h 50^m, the tide goes through the following changes :—shortly after the Moon's transit over the meridian, it is high water, then it begins to decline, and continues falling rather over 6 hours, when low water occurs; after a short rest the waters are again elevated for another period of 6 hours, at the expiration of which there is also high water, our satellite having passed the meridian on the opposite side of the Earth; another brief rest follows, the tide again subsides for 6 hours more, and there is low water for the second time; during the rest of the lunar day the seas are rising, until at the end of the 24^h 50^m we have again *high* water. Sometimes the interval between two successive times of high water is shorter than half the lunar day, at others a little longer.

We see that the waters are high when the Moon is near the meridian, and low when she is in the vicinity of the horizon. From high to low water, the tide is said to *ebb*, and from low to high water, it is said to *flow*. *Flood* and *ebb* tides are synonymous terms for high and low water.

On an average, it is found that the spring tide is higher than the neap in the proportion of seven to three; wherefore, at new and full moon, the sea rises, on an average, more than twice the height that it does at either first or last quarter. When the waters rise highest, they fall the lowest, and when they are least elevated at high water, they recede also the least: this is in consequence of the united action of the Sun and Moon, which causes a great rise and fall at the *spring* tides, and a comparatively small one at the *neaps*, as we have already seen from figs. 21 and 22.

Hitherto reference has been made only to variation in the relative positions of the Sun and Moon in connection with the tides; but there are other astronomical conditions tending to vary the amount of disturbance upon the ocean at different times. Thus the Moon's action is strongest when she is nearest to the Earth, and sensibly less when most remote from us. Her declination or distance north or south of the equator has also a very material influence on the height of the tides; and the same remark will apply less forcibly to the Sun.

Besides the astronomical causes operating to vary the height of the tides, they are affected greatly by local and other circumstances, which render the prediction of the times and height of the tides liable to considerable uncertainty, particularly as regards the latter. Violent winds, for instance, blowing up the river Thames on those days when the spring tides occur, have frequently caused so great an influx of water, as to be productive of serious injury to property in London; whereas at other times, under the same *astronomical* conditions, but without a gale of wind, the elevation of the water in the river is comparatively moderate. In the Mediterranean and Baltic, both inland seas, the tides are scarcely appreciable, for the inlets to these seas are so narrow, that the ocean has not time to fill them with the tidal wave, before the attraction of the Moon is reversed, or tends to make the waters ebb. But on some parts of the Canadian coast the tides rise seventy feet and upwards.

The highest spring tide in London is usually the third or fourth after new or full moon. At Brest, on the French coast, it arrives 23^h sooner. These differences are due to local agencies, and are quite independent of the primary action of Sun and Moon.

REFRACTION.

The Earth is surrounded by an atmosphere which extends several miles above the surface. Its limit is not accurately known, but its density diminishes as the height increases, and it is certain that the altitude of the upper regions of the atmosphere bears but a small proportion to the Earth's diameter, probably not exceeding $\frac{1}{200}$th part.

Now, it is an established law in optics, that when a ray of light passes from a rare medium into one of greater density, it is deflected from its original course, and bent more and more towards the perpendicular, as the density of the medium traversed by it increases. A ray of light, therefore, entering the Earth's atmosphere, and approaching the surface, continually encounters a denser medium than that it has previously passed, and when it reaches the eye of a spectator, will appear to come from a different direction than the true one with which it entered the higher portion of the atmosphere. This phenomenon is called *Refraction*.

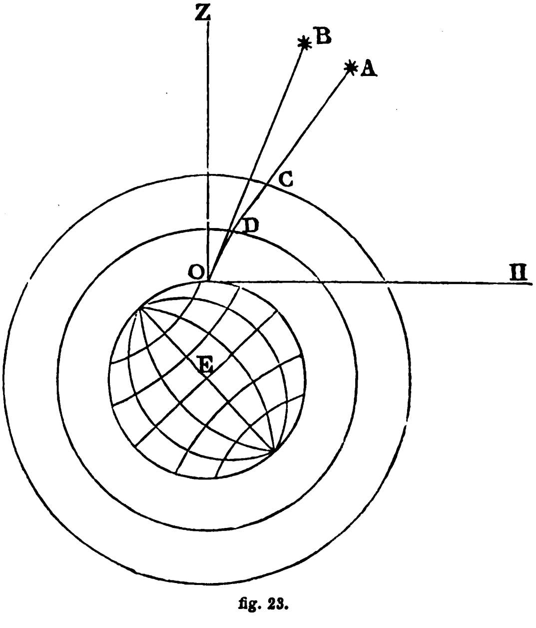

fig. 23.

To explain the effect more particularly, we shall have recourse to fig. 23, where E represents the Earth surrounded by its atmosphere. At the distance of the first circle, on which D is situated, the density of the atmosphere is far greater than at C, a point on the outer circle; it increases gradually from the upper region of the air at C, towards the surface of our globe. Suppose A to be the true place of a star in the heavens, and O the position of an observer; the light of the star entering the higher region of the Earth's atmosphere at C, where, though of extreme tenuity, it is denser than the surrounding space, immediately begins to be deflected from its original course, and as it progresses towards the spectator becomes more and more so, until at O it will appear to have proceeded from B, and the observer would refer the star to that point, though its real position is at A: hence the star is *raised* towards the zenith (Z) by the distance from A to B, which is the amount of refraction.

It is therefore obvious that in general we do not see the heavenly bodies in the positions they really occupy in space: they are elevated in the vertical circle passing through the zenith, for refraction always acts in this direction, that is, in a plane perpendicular to the surface of the Earth. The stars are most affected by it near the horizon, because their light has then to pass through a greater extent of the denser portion of the atmosphere, as would be the case with a star at H, in the engraving annexed. On the contrary, at the zenith there is no refraction; its influence being always exercised, as we have just remarked, in a perpendicular plane, the light of a star so situated reaches the eye of the spectator in its true direction.

The amount of refraction in the horizon is rather over 33′, whence it diminishes far more rapidly at first than afterwards, until it disappears altogether at the zenith. Half-way between this point and the horizon, its influence is to the extent of about 1′ of arc. The refraction, however, is not always the same at a certain altitude; it is affected by changes of temperature and of the height of the barometer, which exhibits the degree of pressure of the atmosphere: the denser the atmosphere, the more will the light of a star be deflected from its true direction.

The horizontal refraction exceeding 33′ is greater than the average apparent diameter of the Sun or Moon (about 32½′), and consequently those luminaries appear to be wholly above the horizon, when they are in reality just below it. The effect of refraction is to hasten the rising of the Sun and other heavenly bodies, and delay their setting beyond the true moments; and for this reason the length of day, from apparent sunrise to sunset, exceeds its length, independently of refraction, by several minutes.

The distorted form of the Sun and Moon when near the horizon is an effect of refraction, which is not of the same amount at the upper and lower points of their discs: if the lower edge be just upon the horizon, it is affected by refraction to the extent of 33′; while the upper edge, being 32′ nearer to the zenith, only undergoes a deflection of 29′; and the vertical diameter will therefore appear 4′ less than the horizontal one; this gives an oval or elliptic figure to the Sun and Moon, which quickly vanishes as they rise higher in the sky, and approach those altitudes where refraction changes more uniformly.

Refraction causes the astronomer no little trouble in his observations: it must be allowed for, before they are available for accurate purposes, and a perfect table of refractions is therefore a most important desideratum. Great progress has been lately made in our knowledge on this subject.

Ptolemy of Alexandria, and other ancient observers of the heavens, appear to have remarked the effects of refraction on the rising and setting of the stars, which they suspected to be different in certain conditions of the atmosphere from what they were at others. Tycho Brahe is supposed to have first constructed a table with the amount of the correction at various altitudes.

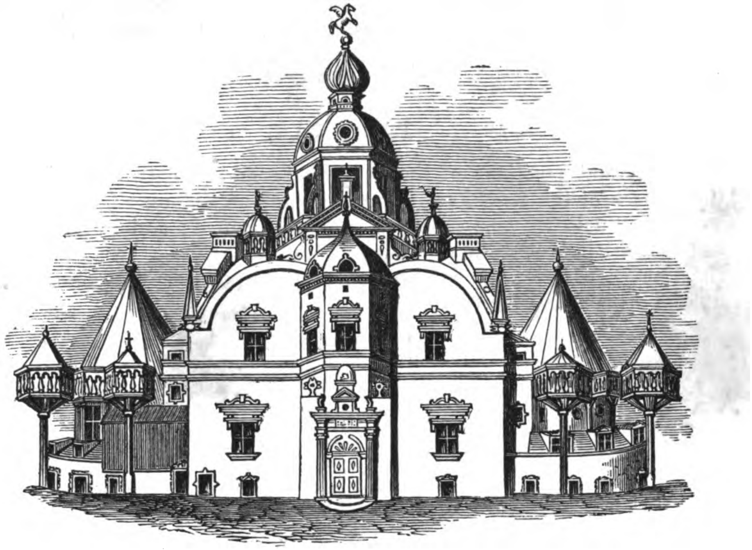

fig. 24. Tycho Brahe's House and Observatory.

TWILIGHT.

The glow of light after sunset in the western sky, and before sunrise in the opposite quarter of the heavens, which we call *twilight*, is caused by the refraction and reflection of the solar rays from the earth's atmosphere.

After the Sun has descended below the horizon, his rays still fall upon the atmosphere, and the light is reflected therefrom to the Earth's surface by vapours prevailing at these altitudes. It becomes fainter as the Sun sinks lower, or accordingly as his rays attain only the higher strata of the air; and when his angular distance below the horizon amounts to 18°, twilight ceases, because at that depression his light falls so far above the Earth, that there is no atmosphere of sufficient density to reflect it again.

The evening twilight is usually longer than that in the morning; a circumstance probably to be attributed to the greater prevalence of vapour in the lower portions of the atmosphere after sunset than before sunrise.

In this country, in the latitude of London for instance, there is, astronomically speaking, no *night* for a month before and after the summer solstice, about June 21st. The Sun is then on the tropic of Cancer, at a north declination of 23½°, in which position he never descends so much as 18° below the horizon, nor does this happen during the previous or subsequent month. There is consequently a continual *twilight* throughout the interval.

Twilight is properly limited by the time which elapses from the moment when the Sun is actually beneath the horizon of a place, and his arrival at a depression of 18° below it. During the early part of this interval the reflected sunlight is so strong that, in ordinary language, it is still called daylight. The above is the astronomical definition of twilight.

PARALLAX.

The apparent positions of the Sun, Moon, and planets, as viewed from the surface of the Earth, are, in most situations, different from what they would be could they be observed from her centre; and in astronomical calculations it is necessary to take account of the difference, because it is the Earth's centre, and not any part of the surface, that describes the annual orbit round the Sun.

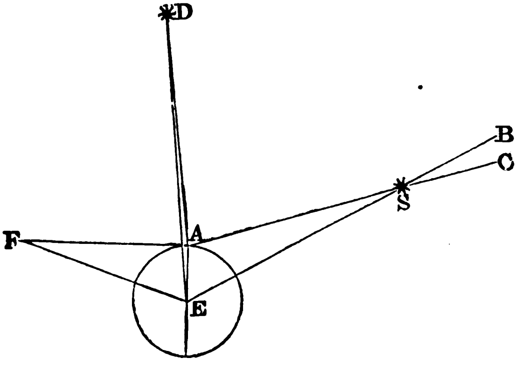

fig. 25.

In fig. 25 suppose A to be the station of an observer at any place upon the surface of our globe, and E its centre. A planet at S will appear to the spectator at A in the direction A C, while if it could be viewed from the centre, its direction would be in the line E B; it is therefore seen from A at a point in the heavens *below* its position in reference to E. The inclination of the lines A S and E S, which measures the difference, is called the *parallax* of the planet.

The effect of parallax is in all cases to depress the Sun, Moon, and planets below the positions they would appear to occupy from the Earth's centre, that is, it brings them nearer to the horizon.

The closer a body is to the Earth the greater its parallax, as will be manifest from a little consideration of the above figure, where, if we had placed the point S as near again to A as it is there given, the lines A S and E S would be much more inclined than they are actually drawn; and, on the contrary, if S were removed to twice the distance from A that it is in the figure, the two lines would be less oblique to each other than as they stand. For this reason the distant planets have smaller parallaxes than those nearer the Earth. The fixed stars appear in the same situation from whatever part of the Earth they may be viewed, which proves their distance from us to be very great.

The effect of parallax upon the Sun, Moon, or a planet, varies also according to its position with respect to the observer. If the body be in his horizon, as at F, the effect is greatest, and is then called the *horizontal parallax*, which is, in fact, the measure of the Earth's semidiameter AE, as seen from the body at F. Thus, the Sun's horizontal parallax is the angle subtended by the Earth's semidiameter at that luminary. If the body be situate in the zenith, there is no parallax, and it would be very small at a point near the zenith; at D, for example, the lines AD and ED nearly coincide.

While the effect of refraction is to raise an object in the vertical circle passing through the zenith, parallax depresses it in the same.

The signification here given to the term 'parallax,' is not its only acceptation. We have remarked that the stars exhibit no appreciable change of place from whatever part of the Earth they may be viewed. They are so remote, that it is impossible to discover the smallest difference in their positions, whether seen from London, for instance, or from its antipodes. In the hope, however, of detecting some such change, which would afford an indication of the actual distances of the stars, astronomers, instead of adopting the Earth's diameter, which is not quite 8000 miles, as their measuring-line, have recourse to that far greater alteration in the position of the observer arising from the Earth's revolution round the Sun; and by observing the stars at opposite points in her orbit, which will be separated by no less than 190 millions of miles, they can ascertain what influence this enormous change of station has upon their apparent places in the heavens. Yet even with this distance as a measuring-line, they have failed to discover any sensible variation in the positions of the stars, except in a very few cases, which will be noticed in the sequel.

The alteration in the place of a heavenly body arising from the diurnal motion of the Earth upon her axis, which brings it into different directions with respect to the observer, is sometimes called the *diurnal parallax*; and that much smaller change of place remarked in a few of the stars, which is due to the annual motion of the Earth round the Sun, is called the *annual parallax*. More frequently astronomers use the term parallax without any qualification; but if it be applied to the Sun, Moon, or planets, it means the difference between their places as seen from the Earth's centre and a point upon the surface; while if the word be used in reference to the stars, it expresses the minute variation in their positions, according as they are viewed from one side of the Earth's orbit or the other.

THE SOLAR SYSTEM.

THE Sun, with his attendant planets, primary and secondary, and that numerous class of nebulous or cloudy-looking bodies, only occasionally visible to us, termed *comets,* form together what is called the SOLAR SYSTEM.

The motions of every member of this system are in accordance with the laws of gravitation, as expounded by Sir Isaac Newton.

fig. 26. **Birth-place of Sir Isaac Newton, Woolsthorpe Manor-house, Lincolnshire.**

Of the planets it may be observed that they have many characteristics common to them all.

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

(2.) They describe oval or elliptical paths about the Sun, not, however, differing greatly from circles.

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

(4.) They are opaque bodies like the Earth, and shine by reflecting the light which they receive from the Sun.

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

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

APPARENT MOTIONS OF THE PLANETS: THEIR CONJUNCTIONS, GREATEST ELONGATIONS, STATIONARY POINTS. HELIOCENTRIC AND GEOCENTRIC PLACES. SYNODIC REVOLUTIONS.

To a spectator placed upon the Sun, the whole of the planets, inferior and superior, would be seen to follow their true course round that body in the order of the signs of the zodiac. Any diminution or increase in their velocities that might be noticed, would be owing to an actual diminution or increase in their rates of progress; in short, all the appearances presented to the observer would be *real.*

It is very difficult when, as in our own case, the planets are seen from a globe which is itself in motion round the Sun. They do not always appear to us to be following the course in which we know they must be moving. Hence it is important to trace out and carefully distinguish those changes which are merely apparent, depending on an alteration in the position of the spectator, combined with the true motion of the planet in space.

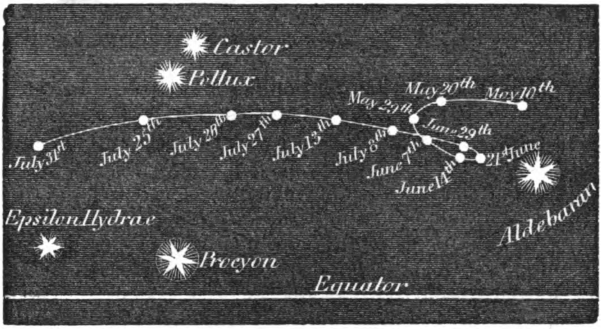

fig. 27. Apparent path of the planet Mercury amongst the stars during a whole revolution in 1850.

The apparent motions of an inferior planet differ greatly from those of a superior one. The former is never seen in those parts of the heavens which are opposite to the Sun's place at the time of observation; it is sometimes to the east, and at others to the west of the Sun, but cannot recede from him so much as 90°, or one-fourth of the circumference. Twice in every revolution it is in conjunction with the luminary; once when its situation is between the Earth and the Sun, called the *inferior conjunction;* and again when the Sun is between the planet and the Earth, this is termed the *superior* conjunction. When the planet attains its greatest distance from the Sun east or west, it is said to be at its *greatest elongation,* eastward or westward as the case may be. Its apparent course in the ecliptic is usually in the order of the signs; but at certain points in the orbit it appears for a brief interval without motion: these are called the *stationary points.* At other periods its apparent motion is reversed; the planet seems to be moving contrary to the succession of the signs, and therefore retrogrades or goes backward upon the ecliptic. Still its *real* course is invariably in the same direction: as we have just remarked, it is the motion of the Earth combined with that of the planet which gives rise to these apparent variations.

In fig. 28, S is the place of the Sun, A B C D the orbit of an inferior planet within that of the Earth at E; K L M N is the path of a superior planet; and the outer circle with the twelve zodiacal signs is intended to represent the ecliptic, on which the longitudes of the heavenly bodies are counted.

To a person upon the Earth at E, the inferior planet will be in conjunction with the Sun at the points B and D; and agreeably to the definitions given above, it is the *inferior* conjunction at B, and the *superior* one at D. The greatest elongations occur near the points *d* and *e*, where lines drawn from the Earth to the Sun and planet respectively, attain the greatest possible inclination or obliquity to each other: at *d* the direction of the planet's motion is nearly in a line *towards* the observer on the Earth, and at *e* it is as nearly in a straight line *from* him; it will therefore appear to him for a short time without motion, near each of these positions, which are the *stationary points.*

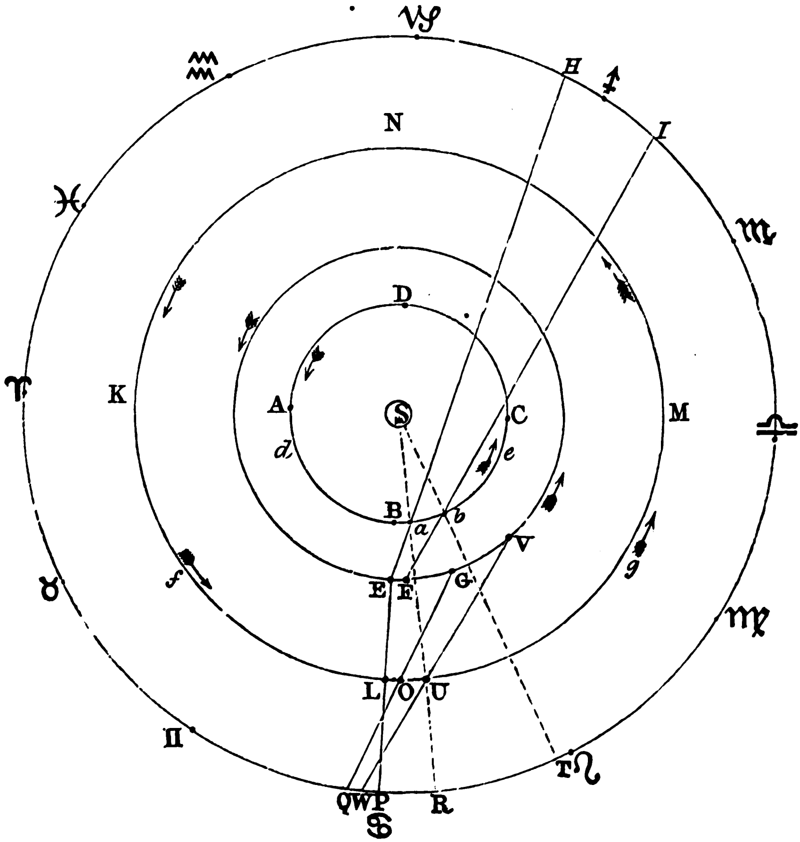

fig. 28.

To explain the cause of retrograde motion in an inferior planet, we will suppose it to be at *a* when the Earth is at E, and that it advances in its orbit to the point *b*, while our globe moves on to F, the arc *a b* being longer than E F, because the nearer a planet is to the Sun, the greater its velocity. Now, a spectator at E, noticing the position of the planet at *a*, will refer it to the point H in the ecliptic, corresponding in our figure to about 7° of the sign Sagittarius; but when he is carried forward to F, it will appear to him at I, a point less advanced upon the ecliptic than H; so that during the interval occupied by the Earth in moving through the space E F, the planet would seem to *retrograde* from H to I, or from Sagittarius into Scorpio. Yet its actual course from *a* to *b* is direct, or in the order of the signs; and to a person observing from the Sun at S, such would have been its apparent motion (from R to T) in the interval.

We may here take occasion to explain the meaning of the terms *geocentric* and *heliocentric*, continually used in astronomy in reference to the positions of the planets or other heavenly bodies. Suppose the planet at *a;* its situation in the ecliptic, viewed from the Earth at E, will be at H, but as seen from the Sun it must appear at R; the one point is in Sagittarius, the other in Cancer: H is called its *geocentric* place, that is, its place as seen from the *centre of the Earth;* R is the *heliocentric* position, or the point it occupies in reference to the *centre of the Sun.* In the case of an inferior planet the heliocentric and geocentric positions always differ more or less, except at the superior conjunction, when the longitude is the same whether seen from the Earth or Sun. At the inferior conjunction, a person on the Sun would see it in the opposite part of the ecliptic to that in which it would appear to be as viewed from the Earth.

It is evident from the figure that the inferior planet can at no time come into *opposition* with the Sun. It is visible in the evenings when to the east of him, and in the mornings when it is on the west side. In superior conjunction at D, the solar rays prevent our discerning it; for at that point it is either behind the luminary, or more commonly a little above or below him. In inferior conjunction at B, it as frequently happens that the planet is rather to the north or south of the Sun, but so near his disc as to be invisible: on rarer occasions, it passes directly between the Earth and the Sun, and is consequently projected upon his surface, appearing like a round black spot in its progress across the disc from west to east. This interesting phenomenon is termed by astronomers a *transit,* and will be more particularly described presently.

The superior planet, moving in the orbit K L M N, is in opposition to the Sun at the point L, the Earth being at E. This is the most favourable time for observing its telescopic appearance, because it is not only nearest to the Earth, as will be seen from the figure, but it is then on the meridian of a place about midnight, when the Sun is at his greatest depression below the horizon, and for this reason it can be longest observed in a dark sky. At the point N the planet's longitude, as viewed from the Earth at E, will be the same as that of the Sun; in other words, it is in *conjunction* with the luminary at N, and cannot be discerned for some time before and after its arrival at this point, through the overpowering brightness of the solar rays. At the two points where the geocentric longitudes of the Sun and planet differ 90°, the latter is said to be in *quadrature* with the Sun; one of these points will fall at *f,* between K and L, and the other at *g,* between L and M. As a general rule the quadratures will occur nearer to K and M, the more distant the orbit of the planet is from the Sun.

The superior planets appear to move in the order of the signs during a great part of the year, but for a certain period their course is reversed; they are always retrograde near opposition, and stationary shortly before or after.

Suppose the Earth to be at E when the planet is at L, and that we move on to G during the time occupied by the planet in advancing to O, the arc E G being in this case longer than L O, contrary to what takes place with an inferior planet. At E we should refer the body at L to the point P in the ecliptic, corresponding, in our figure, to the beginning of the sign Cancer; but at G it would appear to us at Q, in the sign Gemini, having gone back upon the ecliptic through the space P Q. Now, assume that the Earth has travelled on to V, while the planet has moved to U; we should then see it at the point W, which is between Q and P; wherefore its apparent course will have become *direct*, and at a point not far from Q it must have appeared to us without motion. After this it will continue direct until the Earth has completed a large portion of her annual orbit, as will be evident by setting off equal arcs, as E G, G V, and L O, O U, upon the two circles respectively, and extending the lines joining them to the ecliptic, as we have done in the figure: the points of intersection will thus be found more and more advanced until the Earth again approaches E.

The interval of time between two successive conjunctions or oppositions of a superior planet is called its *synodical* revolution, not thereby implying that it has really completed a whole circuit of the heavens in this time, but that the relative motion of the Sun and planet has again brought them together, or diametrically opposite to each other. The synodical revolution will be longer for a superior planet comparatively near the Earth, as Mars, than for one further distant, as Neptune. Mars moving so much quicker than Neptune, advances considerably further in his orbit while the Earth is performing one revolution about the Sun; and the luminary has to continue its apparent course much longer over the year, in order to overtake the planet Mars, than he has to come up again with Neptune.

The further the planet is from the Sun, the nearer will its synodical revolution approach to the length of the Earth's sidereal period ($365^d\ 6^h$), though it must always somewhat exceed it.

PHASES AND APPARENT DIAMETERS OF THE PLANETS.

The inferior planets Mercury and Venus present every variety of phase, from the fine crescent to the circular disc, like the Moon in her revolution round the Earth. This arises from the alteration in the position of their illuminated hemispheres (which are always towards the Sun) with respect to the Earth, and will be more readily understood from an examination of fig. 29, where A, B, C, D, &c., are different positions of one of the above planets—Venus, for instance, in her orbit round the Sun at S, the Earth being in the direction of the arrow. At A, the whole enlightened disc is turned directly towards our globe; but this being the superior conjunction, the planet is lost in the Sun's rays, and therefore the inferior planets are never seen with circular figures, like the full Moon. A little before or after it arrives at this point, it may be discovered with the aid of a telescope, as at B; in this position the Sun does not illumine the whole of that hemisphere which is turned towards us—a portion on the left side is in darkness; and hence the planet has a gibbous appearance, like the Moon between first quarter and full. At C the bright part, for a similar reason, is still less; and at D the planet shines with only half its disc illuminated. At E and F the enlightened part assumes the form of a crescent, like the Moon in her approach to conjunction, after passing her last quarter; for at these points a large portion of the hemisphere next the Earth is turned away from the Sun, and therefore receives no light from him.

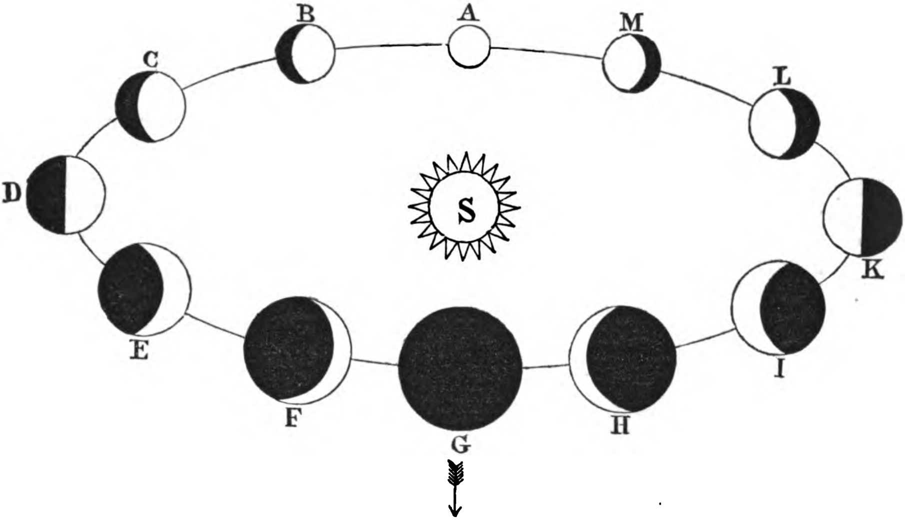

fig. 29.

The crescent becomes less and less as the planet draws near to G, the inferior conjunction, where its dark side is wholly directed towards us, and it will again be invisible, except on those rare occasions (to which reference has been made), when it passes in a line with the Earth and Sun, and appears like a round black spot upon the surface of the latter.

The apparent diameter of an inferior planet varies considerably according to its distance from the Earth. When more than half the disc is illuminated, it is in the further half of its orbit, and consequently appears much smaller than at those times when its bright surface is less than a semicircle, being then in the half of its orbit which lies between the Earth and Sun.

The phases presented by the planets Mercury and Venus afford one proof that their orbits must be included within the Earth's, otherwise it would be impossible to explain their varying forms.

Mars, the first of the superior planets in order of distance from the Sun, is the only one that exhibits any very sensible change of figure, the others being so far removed from us that their visible and enlightened hemispheres nearly coincide; and for this reason they always appear to us with bright round discs. The variations in the figure of Mars are confined within much narrower limits than those of Mercury and Venus. In opposition he is quite round or full, and at conjunction would present the same form if not obscured in the solar rays. At other times he is *gibbous*, the illuminated portion of his surface being smallest at quadrature, but always greater than a semicircle; whence we adduce a decisive proof that his orbit is exterior to that of the Earth, but within the orbits of the other superior planets which offer no variety of phase.

Jupiter, the next large planet beyond Mars, is not strictly speaking round or fully illuminated near his quadratures, but the deficiency is so minute as to be inappreciable to the eye, even with powerful telescopes, and it is only for the most accurate purposes that astronomers take account of it.

METHOD OF FINDING THE DISTANCE OF THE EARTH FROM THE SUN BY THE TRANSITS OF VENUS.

The transits of Venus over the Sun's disc afford the best means of ascertaining the true distance between the Sun and the Earth, but it unfortunately happens that they are very rare phenomena, and only two have yet been sufficiently observed to prove of service in the determination of this important quantity: one of these occurred in 1761, and the other in 1769.

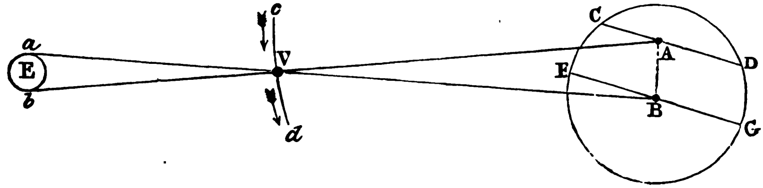

fig. 30.

Fig. 30 will serve to illustrate the principle upon which the transits of Venus are made subservient to this special purpose. E is the Earth, V the planet moving in the direction of the arrow; the large circle represents the Sun's disc. When Venus comes between the Earth and Sun at V, an observer at a point *a* upon the former would see the planet projected upon the Sun's disc at B, and a person stationed on the opposite side of the Earth at *b* would see the planet at A; the distance A B is the difference in the position of Venus on the Sun, due to the difference between the two stations on the Earth's surface, and the wider these are apart, the greater will be the displacement. Now, the angles formed by the straight lines *a* B and *b* A on each side of V are equal, and *a b* will therefore bear the same proportion to A B that the distance of Venus from the Earth does to her distance from the Sun: this proportion is known from Kepler's third law. To find the extent of A B, it is only necessary to observe the times when the planet moving from *c* to *d* enters and leaves the Sun's disc, as we have then the intervals occupied in describing the lines C D and F G, to the observers at *b* and *a* respectively; we can thence determine the exact course of the planet across the disc, as viewed from each station, and consequently the distance A B. Knowing this quantity, and likewise the distance between the observers' stations on the Earth's surface, it is easy to ascertain how great an angle the Earth's semidiameter or half the distance *a b* would subtend, as seen from the Sun, by reducing its measure upon the disc of the luminary, in the proportion of the distances between the planet and the Sun, and the planet and the Earth. This angle is called the Sun's horizontal parallax, being in fact equal to the difference in the Sun's position due to parallax, as seen from the terrestrial pole and equator. Having thus found the apparent breadth of the Earth's semidiameter at the Sun, its proportion to the whole distance between the two bodies is known, and thence we deduce the true distance by simply multiplying the semidiameter of the Earth in miles by the number of times it is contained in the above distance.

From a great number of observations upon the transit of Venus in 1769, it appears that the *equatorial horizontal parallax* of the Sun, by which is implied the apparent semidiameter of the Earth at the equator seen from the Sun at his mean distance, is a little over 8½″; and hence we infer by trigonometry, that the solar distance exceeds the radius of the Earth 24,065 times; and as the former measures 3963 miles, the interval separating us from the Sun must extend to 95,370,000 miles.

The entrance of Venus upon the disc of the Sun is called her *ingress*, and the departure from it her *egress*. As the planet subtends a considerable breadth when projected upon the surface, it is necessary, in order to find the precise moment when her centre coincides with the Sun's border or limb, to note the times when she first touches it on the outside, and when she is just wholly within the disc, as at A and B in fig. 31. A is called the *external*, and B the *internal* contact. Similarly on the planet's leaving the Sun, the same phenomena are noted as at D and E. When it arrives at C, the *least distance of centres* is said to take place, because this is the nearest point of approach between the middle points of Sun and planet.

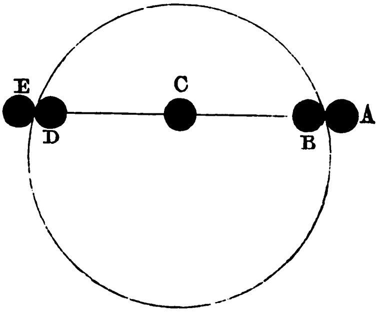

fig. 31.

THE SUN.

The magnitude of the Sun is worthy of the important position he occupies as the centre of our system. His diameter is found to be no less than 888,000 miles, or 112 times greater than that of the Earth, and nearly four times the breadth of the Moon's orbit. A mountain upon the surface of the Sun, to bear the same proportion to his diameter that the Dhawalagiri or highest peak of the Himalaya does to the diameter of the Earth, would require to be 600 miles in altitude.

The circumference of this stupendous globe measures 2,789,000 miles; compared to which, the span of our own planet, though it extends to 25,000 miles, seems quite insignificant.

There is no sensible difference in the Sun's diameter, whether it be measured in a vertical or horizontal direction. It subtends an angle of from 31½′ to 32½′, according to the distance from the Earth.

The mass of the Sun, by which is implied his attractive power, exceeds that of the Earth 356,000 times, and is 740 times greater than the masses of all the known planets put together.

The solar volume or bulk exceeds the Earth's 1,405,000 times; or, which amounts to the same thing, it would take 1,405,000 Earths to make one globe of the same magnitude as the Sun. It is 600 times greater than the contents of all the planetary bodies known to exist. These facts afford a striking illustration of the enormous size of the central luminary.

A body weighing one pound at the Earth's equator, would, if transferred to the Sun, weigh twenty-nine pounds. Hence, no being similarly constituted to man could exist upon the solar orb; for, supposing a person to weigh ten stone, or 140 pounds, on the Earth, he would experience upon the Sun a pressure of 290 stone, which is more than sufficient to crush him.

Astronomers generally regard the Sun as a habitable globe, probably peopled by intelligent beings, though of a differently organised race to ourselves. This appears far more likely than that it should be a vast orb of fire, as the ancients supposed, but, without doubt, erroneously.

The resplendent nature of the Sun is now considered to arise from a luminous atmosphere, or photosphere as it has been termed, which is the source of light, and the partial cause, at least, of heat throughout the system. Of the precise nature of this envelope we are yet ignorant, but that it exists is almost beyond dispute, from the appearances revealed by the telescope.

There are probably three atmospheric strata about the Sun: that supposed to lie nearest his surface is called the *cloudy stratum*, being of a character incapable of reflecting light and heavily loaded with vapours; the next in elevation is thought to consist of an intensely luminous medium, and to this is attributed the diffusion of light and heat; at a greater altitude still, it is probable that there exists a third envelope of a transparent gaseous nature.

The Sun rotates upon his axis from west to east, *i. e.* in the same direction as the Earth, in the space of 25^d 8^h. The axis is inclined 82½° to the plane of the ecliptic, which is intersected by the Sun's equator in longitude 80° and 260°, or in the 20th degree of the signs Gemini and Sagittarius. The north pole of the Sun, therefore, leans 7½° from a perpendicular to the Earth's path in the direction of longitude 350°, which is the 20th degree of the sign Pisces.

These facts have been discovered by attentively watching the black spots, or *maculæ* as they are sometimes termed, which the telescope shews upon the Sun's disc. The spots are found to be neither permanent nor stationary. They sometimes break out suddenly, almost under the gaze of

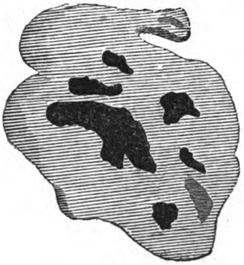

fig. 32. Solar spot.

fig. 33. The same spot, four days later.

the astronomer, continue visible a few hours, and then as rapidly vanish altogether. Others remain for several weeks, or even months, and in this case are found to move across the Sun's disc, entering it upon the western border, or *limb* as it is technically called, and disappearing as they draw near the opposite edge; the time occupied in their transit across the surface is rather less than a fortnight. For a similar period after reaching the eastern border of the Sun, they are invisible to us, but at its expiration reappear on the western edge, and if they last a fortnight longer, again traverse the disc. Some spots have been observed to make seven or eight passages over the Sun before they have vanished entirely.

This motion of the spots in a uniform direction and with a pretty regular velocity, can only be explained by supposing them to adhere to the Sun, and to be carried round by his axial rotation from west to east.

Their forms are often in a state of continual change. As a general rule, there is a black spot included within a greyish shade, which is called the *penumbra*, or several detached black spots of irregular form may be encircled by the same. It has recently been further noticed, that all large spots, and many small ones, have a roundish centre which is densely black, considerably darker than the surrounding portion within the penumbra, the whole of which has commonly been regarded as the *nucleus*, a term that will be more applicable if confined to the circular black centre.

The figures assumed by the dark spot are frequently very curious, and it is interesting to watch them in their progress over the Sun's disc, which is easily done with a telescope of very small dimensions. Great care, however, is required in solar observations: more than one astronomer has lost an eye or seriously injured his sight, by inadvertently omitting to add a dark glass, or from its being suddenly broken by the concentration of the Sun's rays upon it. It is only of recent date that means have been devised by which the large telescopes in observatories can be brought to bear with advantage upon the solar phenomena; one singular result of this practical improvement has been the discovery of a gyratory or revolving motion of the spots themselves, independent of their apparent movement across the disc. It has also been surmised that some of these objects undergo a real change of position upon the surface of the Sun, since the times of rotation given by different spots often differ more than can be accounted for by errors in the observations.

Besides the dark spots, there are others of a more luminous character than the general surface, presenting themselves commonly in the form of bright streaks near those parts where the black spots actually exist, or where they have recently disappeared: these are called *faculæ*.

When examined with a good telescope, the whole disc of the Sun is found to be covered by minute shady dots, which give his surface a mottled appearance. It frequently happens that they seem to be undergoing rapid changes; but it is most likely that this is caused by the variable conditions of the Earth's atmosphere, and consequently is only apparent.

To explain the phenomena of the spots, it is thought by astronomers that the body of the Sun is dark, and that parts of it are rendered visible to us by openings in his atmosphere, through the action of currents, or some analogous agency. These visible portions form the black centres of the spots; the lighter shades surrounding them are assumed to be the cloudy stratum or interior envelope of the Sun, while the penumbra is probably caused by the removal of the upper strata of the atmosphere alone, leaving the lower strata undisturbed. At present we are hardly in a condition to account satisfactorily for all the appearances remarked about the spots, but the foregoing explanation is that on which greater reliance has been placed.

Whatever their primary cause may be, it evidently operates most powerfully near the Sun's equator, the black spots being usually confined to a belt of about 35° on each side of it; on rare occasions only have they been noticed in much higher latitudes.

The *faculæ*, or bright streaks, to which allusion has been made, are generally supposed to be either luminous clouds or the ridges of luminous waves in the upper regions of the Sun's atmosphere. The mottled appearance of his disc, sometimes extending over every part of it, and at others more especially remarked in the equatorial zone, may arise from the contact of the lower or cloudy stratum with the exterior photosphere.

We trace some degree of resemblance between the phenomena of the solar spots, and those of the great ocean hurricanes on our own globe; yet the conditions of the Earth and Sun appear so essentially different, that there is a chance of falling into error, by extending the idea of similar operating agents to both bodies.

The dark spots vary in diameter from a few hundreds of miles to 40,000 or 50,000 miles or upwards. A group of spots, including their enclosing penumbra, will frequently extend over a space of many millions of square miles.

It is by no means an uncommon occurrence for a large black spot or a group of smaller ones to become visible to the naked eye. When the Sun is partially obscured by fog or the vapours of the horizon, a spot may sometimes be thus observed without the use of a dark glass. Several instances of this kind are recorded in ancient chronicles, and of late years, since greater attention has been paid to solar observations, they have become comparatively frequent.

The first discovery of the spots on the Sun with the aid of a telescope has been much disputed. Fabricius, Galileo, Scheiner, and Harriott observed them independently in the years 1610-12, but the priority has been claimed for the first-named astronomer.

THE PLANET MERCURY.

Mercury is the nearest planet to the Sun, and the smallest of those known to the ancients.

His average or mean distance from the Sun is rather less than 37 millions of miles, but his orbit is so eccentric that he is at times nearer to or further from that luminary by 7½ millions of miles; or his greatest distance amounts to 44½ millions, and his least to 29½ millions.

The planet performs a revolution round the Sun in 87^d 23^h, at an average velocity of 100,000 miles per hour, or 30 miles per second.

The apparent diameter of Mercury varies from about five to twelve seconds according to his distance from the Earth; it is least at the superior, and greatest at the inferior conjunction. The real diameter is close upon 3000 English miles, whence the volume or bulk of the planet will be rather more than $\frac{6}{100}$ths of that of the Earth.

The mass is found to be little over the five-millionth part of the Sun's, and the density rather greater than in the case of the Earth.

At no time does Mercury recede from the Sun eastward or westward further than 30°; and as he never sets much more than two hours after the Sun, nor rises before him by a longer interval, he cannot be observed, like the other planets, in a dark sky. The planet twinkles towards dusk like a fixed star with a peculiarly vivid and rosy light; but the young astronomer must exercise a little vigilance and attention, or he may not be successful in identifying it amongst the surrounding stars, during the short time that it can be seen either morning or evening. The modern improvements in telescopes enable us to see the planet in the day-time when it is not very near the Sun's place.

Although Mercury really completes a revolution round the Sun in somewhat less than 90 days, the interval between two inferior or superior conjunctions, or between successive arrivals at the greatest elongation eastward or westward, amounts to 116 days; this is the synodic revolution, which depends upon the relative motions of the Earth and planet.

The transits of Mercury over the Sun's disc take place more frequently than those of Venus, but still are by no means of common occurrence. For a long period to come they can only occur in the months of May and November, because the *nodes*, which are the points where the orbit of the planet crosses the ecliptic, fall in those parts of it through which the Earth passes in the above-named months. Owing to the greater proximity of Mercury to the Sun, his transits are of far less value in ascertaining the distance of that body from the Earth than the transits of Venus. The next phenomenon of the kind will take place on the morning of November 12th, 1861.

The planet is too near the Sun to allow of any exact knowledge of his time of rotation, or the peculiarities of his surface. Schröter, a German observer, is the only one who has ever professed to see indications of mountains or continents upon the disc; he assigned a rotation of $24^h\ 5^m$, but this is assuredly very uncertain.

THE PLANET VENUS.

Venus is the most brilliant of all the planets, her light, which is of a yellowish-white colour, being at certain times so lustrous as to cast a sensible shadow. When visible before sunrise, she was called by the ancients *Phosphorus*, *Lucifer*, or the *morning star*, and when she shone in the evenings after sunset, *Hesperus*, *Vesper*, or the *evening star*.

The orbit of Venus lies between those of Mercury and the Earth, at an average distance from the Sun of sixty-eight millions of miles, from which it varies but little, owing to its deviating very slightly from a circle. A revolution is completed in $224^d\ 17^h$, at a mean velocity of 80,000 miles per hour, or more than 22 miles in a second.

The distance of Venus from the Earth at the inferior conjunction is about 25 millions of miles, and her apparent diameter at the time is nearly 70″; whereas at the superior conjunction she recedes from us to seven times that distance, and her disc then subtends an angle of only 10″.

The true diameter of the planet is 7,800 miles, or very nearly the same as that of our globe; the mass, however, is less, being only $\frac{1}{400000}$th part of the Sun's; the density is $\frac{94}{100}$ths of the Earth's.

Venus is a morning star from inferior to superior conjunction, and an evening star from superior to inferior conjunction. She attains her greatest brilliancy at an elongation of 40° west or east of the Sun, five weeks before and after the inferior conjunction: at this time her apparent diameter is about 40″, and the breadth of the illuminated part 10″; her figure is therefore similar to that of the Moon when five days old. It is at these periods that the planet is bright enough to throw a shadow at night. If, about the time of greatest brilliancy, Venus is also at or near her highest north latitude, she may be seen with the naked eye in full daylight: this occurs once in eight years, in which interval the Earth and planet return to the same situation in their orbits, for eight complete revolutions of the Earth round the Sun occupy very nearly the same time as thirteen revolutions of Venus.

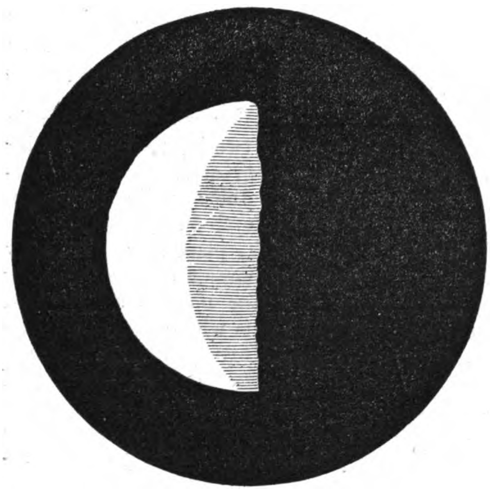

fig. 34. Venus near her greatest elongation.

The sidereal period of the planet being 225 days, it really performs a revolution round the ecliptic in that interval as viewed from the Sun; but the relative motion of the Earth and planet is such as to cause the latter to remain apparently *on the same side* of the Sun for over 290 days, or considerably longer than the above period, while moving in that part of the orbit which is furthest from the Earth. The synodic revolution extends to 584 days, this being the average interval between two conjunctions, inferior or superior.

The surface of Venus, viewed in the telescope, is of an almost dazzling brightness, and for this reason we know little of its nature. Dusky spots are, however, occasionally visible upon it, and by carefully watching them from time to time it has been inferred that the planet rotates upon its axis in 23^h 21^m 21^s, and that its equator makes an angle of 75° with the plane of the orbit. This must give rise to a greater variety of seasons than we experience upon the Earth, and the inequality in the length of the longest and shortest days will be much larger.

The spots of Venus are not supposed to be connected with her surface, but rather appear to exist in her atmosphere. Schröter, the German astronomer, thought he had discerned mountains of great elevation upon the planet, but the observation has never been confirmed.

Viewed from Venus, the Sun would present a diameter of 44′, or nearly half as great again as it is seen from the Earth.

The transits of the planet over the Sun's disc are, as before remarked, of high importance in astronomy, but unfortunately of rare occurrence. They always happen at the beginning of June and December, for a reason similar to that which causes the transits of Mercury to take place in the previous months. The last, which occurred on the 3d of June, 1769, excited very great interest. Several European governments fitted out expeditions to those parts of the world where the phenomenon was likely to be seen to the best advantage. The necessity for having observers at distant stations will be apparent from what has been said respecting the transits of Venus at p. 46. Foremost amongst the governments which interested themselves in the undertaking was that of Great Britain, by which a thoroughly-equipped expedition was despatched to the Island of Otaheite in the Pacific Ocean, under the command of Captain Cook. Observations were taken in Lapland and California, at Pekin, Manilla, Batavia, Jakutsk, Otaheite, &c., and in every part of Europe.

fig. 35. Venus, as drawn by Schröter.

The next transit will happen on the morning of the 8th of December, 1874, but too early to be visible in this country. There will occur another on the 6th of December, 1882, partly visible here; and the succeeding one will not take place till the 7th of June, 2004.

THE EARTH.

The annual circuit of the Earth round the Sun is completed in $365^d\ 6^h\ 9^m$, at a mean distance of 95,370,000 miles, or rather over 12,000 times her own diameter. The circumference of her orbit measures 599 millions of miles, and the mean velocity in describing this enormous distance is 68,000 miles per hour, or 19 miles in a second.

The Earth is nearest to the Sun at the end of December, and furthest from him at the beginning of July, the difference between the greatest and least distances being 3¼ millions of miles.

Her diameter in the direction of the equator measures 7925½ miles, and in the direction of the poles 7899. The difference, 26½ miles, or $\frac{1}{299}$th of the greater diameter, is called the *polar compression*. The circumference at the equator is somewhat less than 25,000 miles.

The Earth rotates upon her axis in $23^h\ 56^m\ 4^s$ mean solar time, which is the length of a sidereal day. The axis is inclined 66° 33′ to the plane of the ecliptic, and retains an invariable position, or is always directed to the same point in the heavens.* The equatorial parts revolve at the rate of 17 miles per minute.

The mean density of the Earth is 5½ times greater than that of water.

THE MOON.

The Moon is the satellite of the Earth, and, as we have seen, revolves about her while she is pursuing her annual journey round the Sun.

It has been stated above that the distance of the Moon from the Earth is 238,000 miles, which is equal to 30 diameters of the latter. This is the average distance; but owing to the eccentricity of her orbit, the Moon approaches us at perigee within 225,000 miles, and recedes from us at apogee to 251,000 miles. Her revolution about the Earth, in reference to the stars, is accomplished in $27^d\ 7^h\ 43^m$, at a mean rate of 2280 miles per hour.

The apparent diameter of the Moon varies, according to her distance, from 28¾′ to 33½′. It is sensibly greater when she is on the meridian of a place than it is when she is near the horizon, because her actual separation from the observer is more than 3000 miles less in the former situation than in the latter. The real diameter is 2160 miles, and is the same whether measured in the direction of the poles or in that of the equator.

The Earth exceeds the Moon in bulk 50 times, and in mass about 80 times. It would therefore require 50 globes as large as the Moon to form one of equal dimensions with our own.

The Moon rotates upon her axis in exactly the same interval that she requires to perform a revolution round the Earth, *i. e.* in one *sidereal* period of $27^d\ 7^h\ 43^m$. In consequence of this she always presents the same side towards us; for the number of degrees passed over by a lunar meridian, in virtue of the rotation, in a certain time, say twenty-four hours, is exactly equal to the average number traversed by the Moon in one day, as seen from the Earth, and hence the same meridian is always directed towards us.

The irregular appearances of light and shade, which are discerned with the naked eye upon the disc of the full moon, are found to arise from the existence of mountains and valleys over the whole visible surface of our satellite. We know that the brighter parts are the more elevated, because, when the sun shines on them obliquely, their black shadows are seen, with telescopic aid, to be projected upon the surrounding plains; while at the

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* Excepting only the minute effect of nutation, before explained.

full moon, when the Sun throws his light upon them in our line of vision, the shadows disappear. By measuring the lengths of these dark shadows, and taking into account the Sun's elevation above their horizon at the time, the true altitudes of many of the lunar mountains have been determined. When the Moon is not near the full, one of her borders (that turned from the Sun) has an irregular ragged appearance, owing to the difference in elevation of those parts then near the limit of the illuminated surface; the higher points, or mountain peaks, being visible as brilliant spots quite detached from the general outline of the Moon, with intervening spaces of various shades, which are the level or more depressed parts. The top of a mountain is thus seen to be enlightened several hours before it forms a part of the illuminated disc.

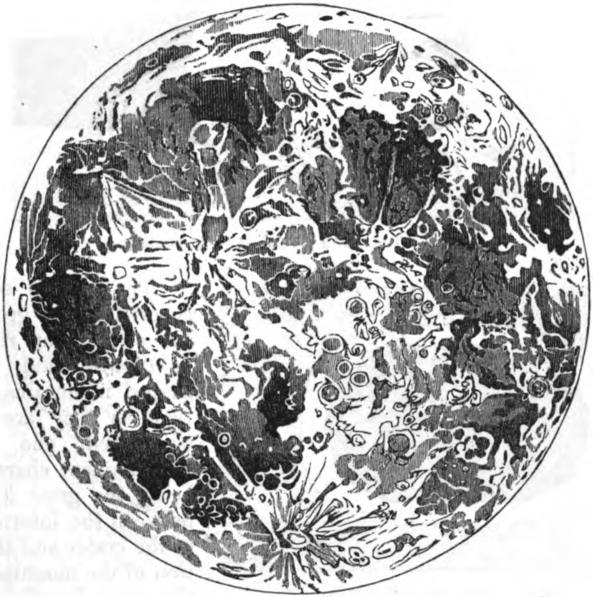

fig. 36. General appearance of the Full Moon.

To distinguish the lunar spots one from another, the great names of classic antiquity and those of eminent moderns, with a few geographical appellations, have been assigned to them by successive astronomers, who have made the features of the Moon their especial study: thus we find Plato, Aristarchus, Eratosthenes, &c., associated with Copernicus, Kepler, and Newton, in addition to such names as the Apennines, the Carpathians, &c.

Some of the extensive shaded regions were called *seas*, and considered to be such by former observers. Amongst them occur *Mare Crisium*, the Crisian sea—*Mare Nubium*, the Sea of Clouds—*Sinus Iridum*, the Bay of Rainbows, &c. These names are in use at the present day, but it is not to be thereby understood that astronomers suppose these dusky portions of the disc to be really the lunar oceans. On the contrary, there is strong evidence to shew that no water exists upon the Moon; and the ancient names are therefore adopted merely as a matter of convenience, or to avoid the confusion which might arise from assigning several names to the same object.

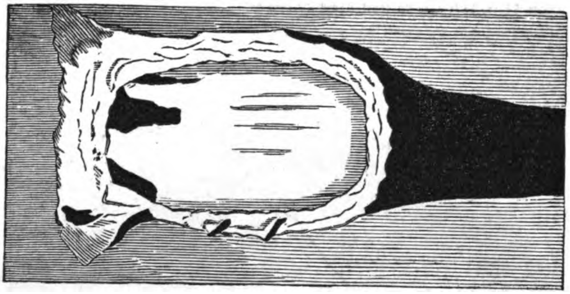

fig. 37. Plato, with the Sun shining obliquely.

The Moon's surface is covered with a great number of annular ranges of mountains, and of cup-shaped mountains, or craters, as they are usually considered, one peculiar and frequent characteristic being the great inequality between the internal depth of the crater and the elevation of the mountain above the general surface of the Moon. Every where we see traces of volcanic agency, though there is no reason to suppose that it has been in operation in recent times.

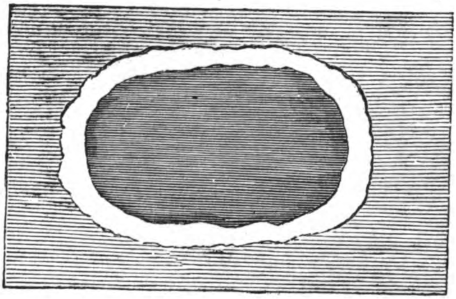

fig. 38. Plato on the Full Moon.

Cavities, or *walled-plains* as they have been termed, are another common feature of the lunar surface: they are of a darker shade than the surrounding region, and evidently depressed at various depths below the general level. Their form is pretty nearly circular, but owing to their

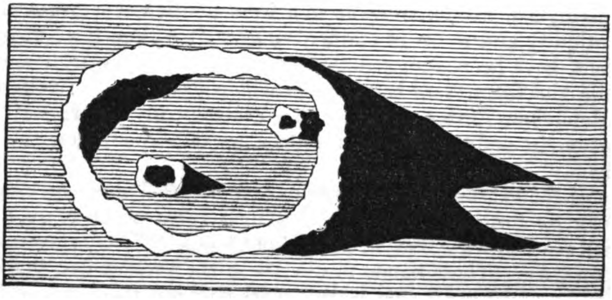

fig. 39. The Annular Mountain Cassini; the Sun shining obliquely.

being frequently viewed obliquely, they present an oval or elliptical outline. *Plato* affords a remarkable instance of a *walled-plain.*

There also occur on the level parts of the Moon rectilinear luminous streaks or hollows, which, before the existence of water upon the surface of our satellite was considered to be disproved, were thought to be the lunar rivers. They are mostly from 20 to 30 miles in length. Their real character is still a mystery.

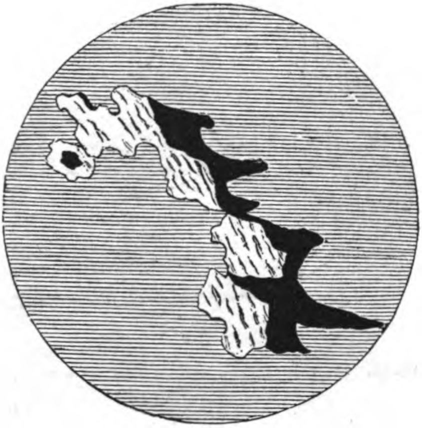

fig. 40. Range of Lunar Mountains and their Shadows.

The altitudes of upwards of one thousand lunar mountains have been measured, and likewise the diameters of the annular ridges of mountains, the craters and principal cavities. Many of the former are found to be of much higher elevation in proportion to the diameter of the Moon, than the most lofty mountains on the Earth in proportion to her diameter. Thus estimated, some of the lunar eminences exceed in height the towering summits of the Himalaya by 3 to 1.

The breadths of the craters are usually much greater than in terrestrial volcanoes: a diameter of 8 or 10 miles is not of unfrequent occurrence. Some of the cavities and annular ranges of mountains, which are clearly of volcanic origin, measure 100 or 120 miles across.

Maps of the whole visible surface of the Moon have been constructed at various times. The most recent are those of Dr. Mädler, a Russian astronomer.

A few days before and after new moon, when the illuminated portion of the disc is only a small part of the whole, the spots and outline of the dark surface are often very distinctly visible, and occasionally brilliant points flickering, as we might suppose volcanoes in action would do, are perceived with the telescope. The cause of this faint greyish illumination of the disc upon which the Sun cannot be shining, is the reflection of light from the Earth: it is in fact *earth-light* on the Moon. For when the Moon is between the Earth and the Sun she has the whole enlightened surface of our planet turned towards her, and since its diameter will measure over 2°, giving an area 13 times greater than that of the Moon's disc as we see it, the quantity of light reflected from the Earth to the Moon must be very considerable. The brilliant points, which were formerly supposed to be volcanoes in action, are now ascertained to be caused by the vivid reflection of earth-light from one or two of the spots which from some special cause offer a surface of greater reflective power than other parts of the lunar disc; the unsteady flickering appearance is no doubt produced by the state of our own atmosphere.

It has been stated that the Moon always presents the same face towards the Earth, and this would appear to be the case to any casual observer.

Strictly speaking, however, it is not precisely so. The Moon's rotation is uniform, that is, it is always performed at the same rate, and therefore in the same time; but her motion round the Earth is not invariably at the same velocity, and hence it happens that we occasionally see a little further round each limb than at other times. Again, the Moon's axis not being quite perpendicular to her orbit, we sometimes are able to see a little more than usual of her north and south polar regions. The former of these effects is termed the *libration in longitude*, and the latter the *libration in latitude*. It might be inferred that these small irregularities would so accumulate in course of time as to bring the other side of the Moon round towards the Earth, but, unfortunately for our knowledge of the physical constitution of that hemisphere, it is proved from the theory of the subject that such changes can only take place within certain narrow limits, and consequently it is impossible we can ever see the other half of the disc.

fig. 41. Probable appearance of the Earth as seen from the Moon.

To the lunarians, if there be any, the Earth will appear nearly immovable in their sky; passing every month through the same phases that the Moon does to us. They may be able to distinguish between the continents and oceans upon our globe, though the prevalence of clouds in the Earth's atmosphere may and most probably would render the outlines of the same very indistinct.

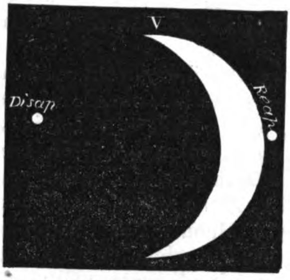

fig. 42. Occultation of a Star by the Moon.

The Moon, in the course of her monthly journey round our heavens, frequently passes before the stars and planets, which disappear on one side of her disc, and reappear on the other. An occurrence of this kind is termed an *occultation* of the star or planet by the Moon. It is a very interesting telescopic phenomenon, and of great practical use in ascertaining the difference of longitude between places on the Earth's surface.

THE PLANET MARS.

Mars, the first of the superior planets, performs his revolution round the Sun in 687 days, at an average velocity of 55,000 miles an hour, or 15½ per second. His mean distance from the Sun is 145 millions of miles; but the eccentricity, which amounts to $\frac{1}{10}$ of the above distance, causes him to approach within 132 millions at perihelion, and to recede to nearly 159 millions at aphelion.

When Mars is nearest to the Earth his apparent diameter exceeds 30″; but at the conjunction with the Sun he would present, if visible, a breadth of only 4″. The true diameter is 4500 miles. There is a sensible compression or flattening at the poles, amounting to about $\frac{1}{50}$th part of the diameter.

The mass is not exactly known, since Mars does not, as far as we are aware, possess a satellite by the movements of which we might approximate closely to his attractive power. It is generally supposed to be about 2½ millions of times less than the mass of the Sun, or only one-seventh of the Earth's. The density amounts to $\frac{96}{100}$ths of that of our globe.

Mars presents a ruddy, fiery appearance to the naked eye, and becomes a bright object in the heavens when he is near opposition. Under telescopic examination, his surface is found to be covered with dusky spots of irregular form, which are presumed to be the outlines of continents and seas; the continents have a dull red tinge, while the seas are greenish. The red colour is very striking in some parts of the surface. At the poles there are brilliant white spots, which are considered to be masses of snow, since they have been observed to grow less as the Sun's influence becomes sensible upon them, and *vice versâ*, to increase on the commencement of their winter.

fig. 43. Mars, near opposition.

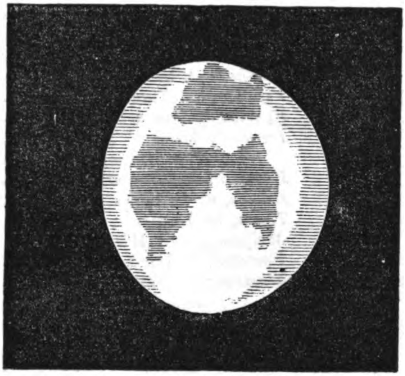

fig. 44. Mars, in a gibbous state.

From observations of the dusky spots, it has been ascertained that Mars rotates upon his axis in 24ʰ 37ᵐ, the north pole being directed towards 350° longitude, and inclined at an angle of 61° to the plane of the orbit. The seasons upon this planet will probably differ little in character from our own, though of nearly twice the length.

Mars appears to have a considerable atmosphere, though not of so extensive or dense a nature as was formerly supposed.

When the planet is near opposition, we see the disc fully illuminated. At all other times it is *gibbous*, approaching nearest in form to a half-moon when it is at the quadratures.

The synodic revolution occupies 780 days; consequently Mars comes into opposition once only in about two years. The most favourable periods for viewing his disc are not so frequent as this, because to be advantageously observed, the planet must be in opposition and perihelion about the same time: he then approaches near the Earth, and his brilliancy is such that he becomes no unworthy rival to the bright planet Jupiter. This can only happen once in about eight years.

THE MINOR PLANETS.

Between the orbits of Mars and Jupiter (the next of the great planets reckoning from the Sun) revolves a remarkable group of small planets, now twenty-five in number. The whole of these bodies have been discovered during the present century, four of them in the early part of it, and the remainder since the year 1845. They are distinguished by female names taken from the mythology of ancient Greece and Rome.

They differ in some respects from the other members of the planetary system, particularly in point of size,—the largest amongst them probably not exceeding 450 miles in diameter. In several cases their orbits are much more inclined to the plane of the ecliptic than those of the great planets; for this reason they are frequently beyond the limits of the ancient zodiac, and have been termed *ultra-zodiacal planets.*

The names of the twenty-five small planets, and of their discoverers, with the dates when they were found, are as follow:—

Ceres, by Piazzi	1801, January 1.
Pallas, by Olbers	1802, March 28.
Juno, by Harding	1804, September 1.
Vesta, by Olbers	1807, March 29.
Astræa, by Hencke	1845, December 8.
Hebe, by Hencke	1847, July 1.
Iris, by Hind	1847, August 13.
Flora, by Hind	1847, October 18.
Metis, by Graham	1848, April 25.
Hygeia, by Gasparis	1849, April 12.
Parthenope, by Gasparis	1850, May 11.
Victoria, by Hind	1850, September 13.
Egeria, by Gasparis	1850, November 2.
Irene, by Hind	1851, May 19.
and by Gasparis	1851, May 23.
Eunomia, by Gasparis	1851, July 29.
Psyche, by Gasparis	1852, March 16.
Thetis, by Luther	1852, April 17.
Melpomene, by Hind	1852, June 24.
Fortuna, by Hind	1852, August 22.
Massilia, by Gasparis	1852, September 19.
and by Chacornac	1852, September 20.
Lutetia, by Goldschmidt	1852, November 15.
Calliope, by Hind	1852, November 16.
Thalia,[*] by Hind	1852, December 15.
A Planet, by Gasparis	1853, April 6.
Phocea, by Chacornac	1853, April 6.

Of these twenty-three planets, *Flora* has the shortest period of revolution, viz. 1193 days, or 3¼ years: her mean distance from the Sun is somewhat over 209 millions of miles. *Hygeia* is the most distant, and therefore has the longest period: her average separation from the Sun is 300 millions of miles, while her circuit round him is accomplished in 2043

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[*] *Thalia* makes the eighth planet detected at the private observatory of Mr. Bishop, Regent's Park, London; so that one-third of the group of minor planets has been discovered in England.

days, or rather over 5½ years. As far as we know at present, the nearest approach to the Sun is made by Victoria in perihelion, and the greatest recession from that luminary by Hygeia in aphelion; for, as happens with the old planets, the orbits of all the new ones are more or less oval or elliptical.

Towards the end of the last century, Professor Bode, of Berlin, had pointed out a singular relation between the mean distances of the planets then known, including Uranus, from which it was conjectured that a planet probably existed between Mars and Jupiter, and it was mainly owing to the strong impression created amongst astronomers by the publication of Bode's relation of distances, that a plan of searching out the latent body was devised and speedily put into execution. This so-called "law" has consequently acquired great celebrity, but has failed, partially at least, in the case of Neptune, which was unknown to Bode. In its most simple form it is expressed as follows :—

To the numbers 0, 3, 6, 12, 24, 48, 96, 192, (in which series, it will be observed, each number after the second is double the preceding one,) add the number 4 in succession, the sums will represent, approximately, the relative mean distances of the planets, including Uranus, that of the Earth being 10 : thus

Adding 4 to 0, the sum is 4, nearly the distance of Mercury.
„ 4 to 3 „ 7, „ „ Venus.
„ 4 to 6 „ 10, which is the distance of the Earth.
„ 4 to 12 „ 16, nearly the distance of Mars.
„ 4 to 24 „ 28.
„ 4 to 48 „ 52, nearly the distance of Jupiter.
„ 4 to 96 „ 100, „ „ Saturn.
„ 4 to 192 „ 196, „ „ Uranus.

This relation indicates a planet between Mars and Jupiter, at a mean distance from the Sun of about 28; and it is curious enough, that Ceres, the first of the new planets in order of discovery, was found to be situated almost precisely at this distance.

The subsequent discovery of Pallas and Juno in the same region led Dr. Olbers to suspect that these small planets are in fact parts of a much larger one, which moved at a remote period near the same mean distance, but by some great convulsion had been shattered in fragments; this idea has received considerable weight from the more recent discovery of so many small bodies belonging to the same group, and the mutual intersection of their orbits in about 180° of longitude, or in the sign Virgo, which has induced some astronomers to think that a great planet may have met with some fearful catastrophe in that part of space.

It is not by any means improbable that in course of time mathematicians may arrive at some direct and general conclusions deserving of confidence with regard to the origin and past condition of the minor planets.

THE PLANET JUPITER.

With the single exception of Venus, Jupiter is the brightest of the planets, and when he is nearest to the Earth his lustre falls very little short of the average brilliancy of the former.

The mean distance of this planet from the Sun is 496 millions of miles;

the corresponding time of revolution is 4,332½ days, or rather under twelve of our years. He travels with an average velocity of 30,000 miles per hour, or 500 per minute.

Jupiter is by far the largest planet in the system; his mean diameter is 88,000 miles, about one-tenth of the Sun's, whence we compute his bulk or volume to be 1300 times greater than that of the Earth, and even to exceed, in the proportion of ten to seven, the solid contents of all the other planets taken together. His apparent diameter varies from 30″ to about 45″, according to distance.

This planet is considerably flattened at the poles, which gives his disc an elliptical outline. The equatorial diameter is to the polar one as 1000 to 950, or exceeds it by about 6,500 miles.

The surface of Jupiter, when viewed in the telescope, appears to be traversed by a number of shaded streaks called *belts*, which are considered to be caused by openings in the atmosphere of the planet, whereby its darker body becomes indistinctly visible: this explanation is strengthened by the fact that the belts do not reach the edges of Jupiter, but terminate at a short distance from them. Generally there are two strongly-marked belts, one a little north, and the other south of the equator, which is quite free from any appearance of the kind, being in fact rather more luminous than the remainder of the disc. Smaller ones are seen nearer to the poles, and these vary more frequently in form than the equatorial belts. The latter are probably of analogous origin to the trade-winds upon the Earth.

Spots of a darker character than the belts have occasionally been visible for a few months in the equatorial regions; and astronomers have availed themselves of the favourable opportunities thus afforded for determining the time of Jupiter's rotation on his axis. From numerous observations of the spots, it is found that the planet is whirled round in the space of $9^h\ 56^m$, which interval is marvellously short when we consider the vast dimensions of Jupiter. The length of day and night will average less than five hours each; nor can this undergo any material change, because the planet's equator is inclined little over 3° to the plane of the orbit. For the same cause there will be one unvaried season on any degree of latitude throughout the year, excepting only over a small portion of the surface round each pole.

The mass of Jupiter amounts to the 1048th part of the Sun's, and is three times greater than the united masses of all the other planets. The effect of his powerful attraction is found to be very important when we examine the motions of the small planets which have just been described. Pallas has in some years possessed a longer period of revolution, in others a shorter one, than Ceres, owing to the attractive influence exercised by Jupiter in his various positions with respect to those bodies and their own comparative minuteness.

Four moons or satellites revolve round Jupiter in the respective periods (roughly speaking) of $1^d\ 18^h$, $3^d\ 13^h$, $7^d\ 4^h$, and $16^d\ 16\frac{1}{2}^h$. Their discovery has been generally ascribed to Galileo. That satellite which is nearest to the planet is called the *first*, the next in order of distance the *second*, and so on. The *third* satellite is the largest of the four; the *second* is about the size of our moon, the other two rather larger; the exterior one being of similar dimensions to the planet Mercury. The mean distance of the first satellite is 278,000 miles; of the second, 443,000; of the third, 707,000; and of the fourth, 1,243,000, which is more than five times the distance of the Moon from the Earth. It is interesting to watch their various configurations with regard to the primary, which may readily be done with the aid of a small telescope. Sometimes all four moons are seen on the same side, or two on one side and two on the other. Frequently three or two only are visible, and less often only one; while on several rare occasions the planet has been seen unattended by a single satellite.

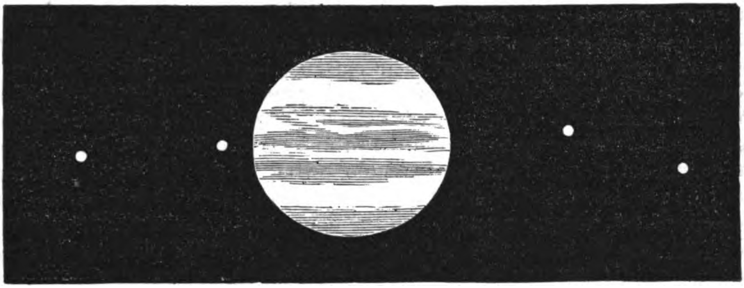

fig. 45. Jupiter and his four Satellites.

It was discovered by Sir William Herschel that the four moons of Jupiter revolve upon their axis in the same times that they travel round Jupiter, precisely as happens with our own Moon. It is probable that this rule applies generally to those planets having satellites. The fact was ascertained from an attentive examination of the relative brightness of Jupiter's four attendants in different positions with respect to their primary.

The satellites also undergo *eclipses* like our Moon, because Jupiter is an opaque body similar to the Earth, and therefore throws a long shadow into space, which his moons must often necessarily traverse. These and other phenomena connected with his system will be better understood from a little consideration of the figure subjoined.

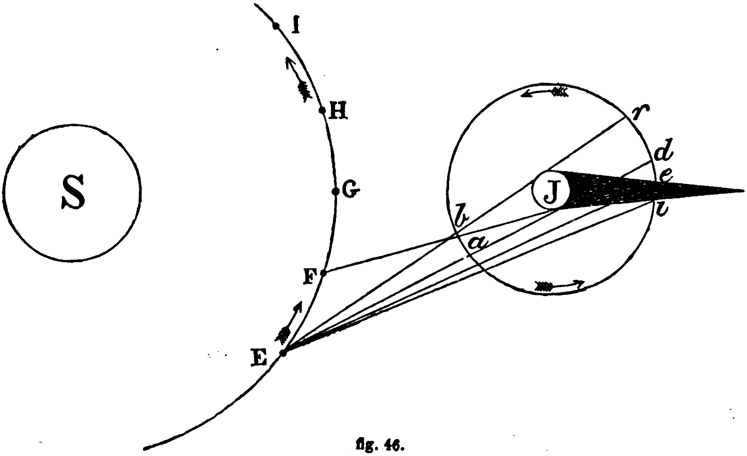

fig. 46.

S represents the Sun, E F G part of the Earth's orbit, J the planet Jupiter casting a dark shadow into space; and *i r b* the orbit of one of the satellites. Now to a spectator on the Earth at E, the satellite moving in the direction of the arrows will enter the shadow at *i*; it will be invisible, because eclipsed, during its passage from *i* to *e*, at which point, being free from the shadow, it would again come into view; *i* is the point of *immersion*, and *e* that of *emersion* with respect to the shadow; and when the Earth is at E before the opposition of Jupiter to the Sun, both points fall some distance from the disc of the planet on its western side. In such a position of our globe, the immersions or entrances into the shadow of the two exterior satellites, and their emersions or departures from it, can be observed; observations of this kind being most preferable for ascertaining the form and position of their orbits. The *first* and *second* satellites revolve at so short distances from the primary that either their immersions or emersions must be always invisible, owing to the planet itself being between them and the Earth; this will be manifest were we to describe a circle round J, with only one-fourth the diameter of that actually drawn; it would then be found that either *i* or *e* falls behind the planet according as the Earth is east or west of the line joining the centres of Jupiter and the Sun. Suppose the satellite to continue its course towards *r*, after emerging from Jupiter's shadow at *e*, that is, after the termination of the eclipse; it will be visible until it reaches the point *d*, where a line drawn from the Earth at E to the satellite would touch the disc of the planet. At this point it again disappears, being hidden from our view by the intervention of Jupiter himself, and remains so until it arrives at *r*, where a line joining the Earth and satellite comes in contact with the other side of the disc, and the satellite reappears. This phenomenon is called an *occultation*.

The point *e* of emersion at an eclipse will fall nearer to the disc of Jupiter as the Earth advances from E; when she arrives at F, the edge of the shadow where it is crossed by the satellite's orbit will coincide with the limb of the planet, and for some time after this happens the immersion only can be observed. At opposition, the Earth being situate at G, in the line of the shadow, all eclipses will occur while the satellites are occulted or hidden behind the planet; about this epoch, therefore, occultations only are visible.

The above explanation applies to the order of the phenomena from the time that Jupiter comes into view in the morning sky, after conjunction with the Sun, until he arrives in opposition to that body, or, as represented in the figure, while the Earth is moving towards G, to the west of the line joining S and J. After this time, as she advances in her orbit through H, I, or as Jupiter, having passed his opposition, appears to close in with the Sun, the eclipses and occultations of the satellites will be observed in reverse order, which may be easily shewn by making the necessary alteration in the figure. The appearances between G and H, and at I, will be similar to those between G and F, and at E respectively, excepting that the immersion of the closer satellites will be invisible while the Earth moves from G to H, instead of its emersions as before. It should also be observed, that at I the occultations will *precede* the eclipses, instead of following them, as was the case before opposition.

When a satellite passes through that part of its orbit which lies between

Jupiter and the Earth, it crosses over his disc, sometimes appearing like a bright spot, at others, singularly enough, of a dark greyish shade; and, because its shadow is projected into space to a distance exceeding that which separates it from the primary, it will, about the same time, fall upon the surface of Jupiter, and traverse it like a small black spot, *preceding* the satellite *before* opposition, and *following* it *after* that epoch. These phenomena are called the *transits of the satellites and their shadows.* Powerful telescopes are required to observe them distinctly.

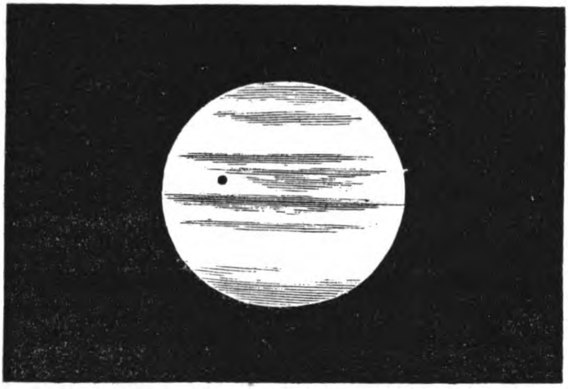

fig. 47. Jupiter, with the shadow of a Satellite upon his disc.

The three interior satellites are eclipsed in every revolution; but the *fourth,* having its orbit inclined at a greater angle to that of its primary, sometimes escapes occultation and eclipse for several successive periods.

It was the attentive examination of the eclipses of Jupiter's satellites, at different distances of the planet from the Earth, that led Römer to discover the progressive transmission of light. He found the observed times of the eclipses were, on some occasions, earlier, and on others later, than the calculated times, and eventually ascertained that the difference depended upon the distance of Jupiter from the Earth. This circumstance convinced him that light is not instantaneously transmitted through space, though its velocity was shewn to be almost inconceivably great, being more than 190,000 miles in a second of time. Römer's conclusion has since been verified by other methods.

THE PLANET SATURN.

Saturn follows Jupiter in order of distance from the Sun; but is separated from him by a space of 414 millions of miles, being somewhat under 910 millions distant from the solar orb. The period of revolution is 10,759 days, or 29½ years; and he moves at an average rate of 22,000 miles per hour, or 6 miles per second.

The apparent diameter of this planet, when nearest to the Earth, is about 18″, the real mean diameter 73,000 miles; but as there is a sensible flattening at the poles, the diameter in that direction falls short of the equatorial one by about 5000 miles. The volume is 770 times greater than the Earth's, and the mass about 3500 times less than that of the Sun.

Saturn revolves upon his axis in $10^d\ 16^h$, which is a little longer than in the case of Jupiter. The axis leans towards the orbit about 63°, and the Saturnian equator and our ecliptic are therefore inclined to each other 29°, the latter being intersected by the former in the 17th degree of Virgo and Pisces, or (which amounts to the same thing) in longitude 167° and 347°.

The surface of Saturn is usually traversed by dusky belts, of a less distinct and definite appearance than those we see upon Jupiter. His equatorial regions are brighter than the other parts of the disc; the poles especially are less luminous. The shaded streaks have a greenish-blue tinge when viewed under favourable circumstances. It was by watching their configuration at different times that Sir W. Herschel discovered the length of Saturn's axial revolution.

The most remarkable peculiarity about this planet consists in the existence of several broad and flat concentric rings, which surround it in the plane of its equator. Some doubts exist amongst astronomers at present with regard to the number of rings; but in ordinary telescopes two are conspicuous, and of nearly equal brightness with the globe of Saturn. The interior one is the widest, and appears to be separated from the other by a narrow black line. Similar fainter lines have been occasionally remarked on both rings, which circumstance has induced the suspicion that they may be composed of several narrow ones. Between the interior bright ring and the globe there has been lately detected another *dark* ring, only discernible in powerful instruments and by a practised eye. This obscure zone is of a purplish colour, while the luminous rings are yellowish, like the planet itself.

The true form of the rings is no doubt very nearly circular; but owing to our always viewing them foreshortened, they are oval or elliptical when the Earth is above or below the plane, and appear, if visible at all, like a single black line crossing the disc, when we are *in* that plane.

There is no change in the true position of the rings during Saturn's revolution round the Sun: they remain continually parallel to themselves.

The plane of the rings is inclined 28° to the ecliptic, and intersects it at present in the 18th degree of Virgo and Pisces; the former point is called the ascending node, because the Earth there ascends from beneath the plane of the rings to their northern side. In a hundred years the points of intersection with the ecliptic advance, in the order of signs, about $1\frac{1}{4}$°.

The various phenomena of Saturn's ring will be easily understood from the annexed illustration, where S is the Sun, T the Earth (her orbit being represented by the smaller ellipse), and A, B, C, D, &c., different positions of the planet in its orbit. Now, when Saturn is in the position A, corresponding to the 18th degree of Virgo, the Sun is in the plane of the ring at its ascending node, and therefore only shines upon its narrow edge, which causes the ring to be invisible except in the most powerful telescopes that have been hitherto constructed. As Saturn advances, more and more of the *northern* surface of the ring comes into view, the ellipse into which it is projected growing wider and wider, until the planet arrives at C, 90°, or one-fourth of the circumference, from the ascending node at A; the Earth is then elevated 28° above its plane, and as this is the amount of inclination between that plane and the ecliptic, we view the ring as much open as it ever can be, the longer diameter of its elliptical outline being then pretty exactly double the shorter one. After the planet passes C, it draws nearer to the opposite node of the ring; we see less and less of the northern surface until it finally closes in at the point E, corresponding to the 18th degree of Pisces. The Sun is now in the plane of the ring for the second time, and it becomes invisible for the same reason as before. Saturn moves on through F to G, and in the mean time exposes more and more of the southern surface of the ring to our view: at G, distant 90° from the descending node, it will be most open; for the Earth is then depressed 28° below its plane. From this point it gradually closes in again until Saturn completes its revolution, and once more comes to the node at A.

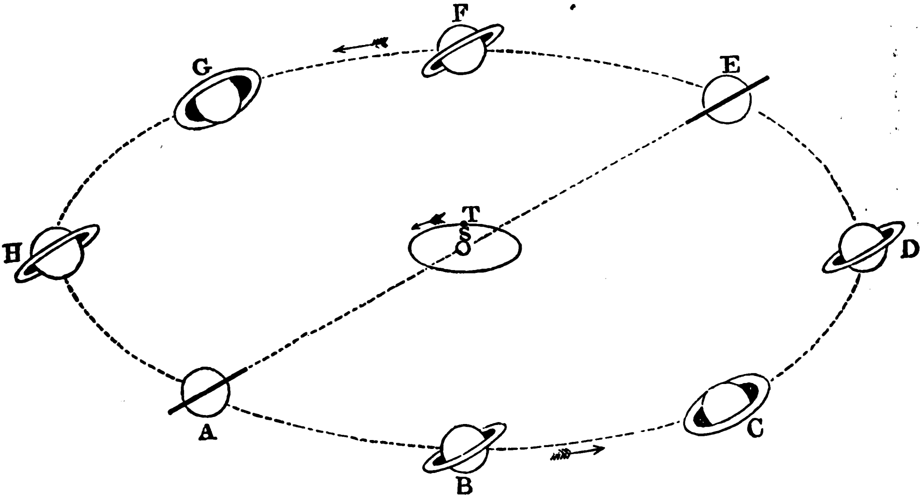

fig. 48.

The successive appearances of the rings are represented in the following engraving, where the letters correspond to the situations of the planet in the above figure.

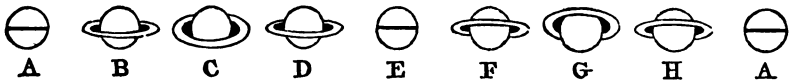

fig. 49.

We see that the rings are most open, and therefore more advantageously seen, when the planet is situate about the middle of Gemini and Sagittarius, and are invisible when it is in the middle of Virgo and Pisces. The northern surface is turned towards the Earth during Saturn's progress from Virgo to Pisces, and the southern surface while he moves from Pisces into Virgo. The period of revolution being nearly thirty years, we see each side of the rings alternately, for about fifteen years or rather less.

The general aspect of the rings is pretty much the same whether viewed from the Earth or the Sun; but the motion of the former in her orbit, which is slightly inclined to that of Saturn, gives rise to certain phenomena of the rings as we see it, that would not be witnessed by an observer placed upon the Sun. Thus it usually happens that there are two if not three disappearances about the time of the planet's arrival at the nodes. The plane of the ring may not pass through the Earth and Sun at the same time, but the ring may be invisible under both conditions, because its edge only will be directed towards us. It is also invisible when the Earth and Sun are on opposite sides of its plane—a state of things that may continue a few weeks; in this case we have the dark surface turned towards our globe. In very powerful telescopes it has been found that the disappearance of the ring is complete under the latter condition: it has, however, been perceived as a faint broken line of a dusky colour, not only when the Sun is in its plane, but likewise when its edge is directed to the

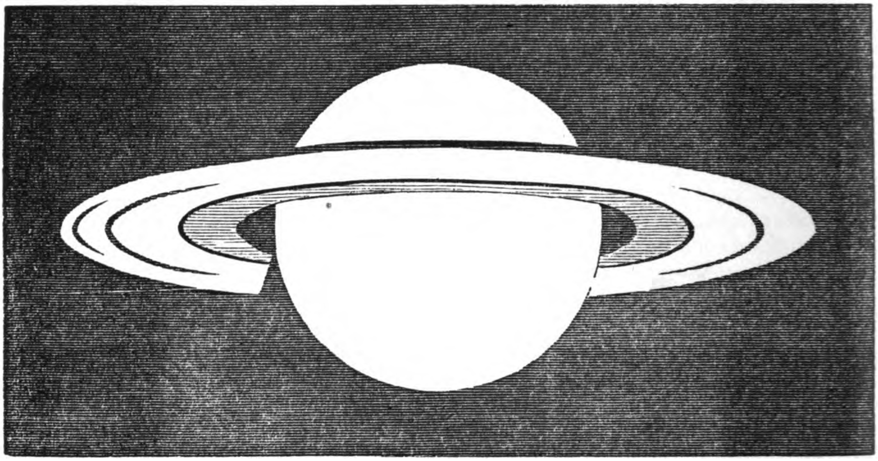

fig. 50. Saturn and his Rings in 1851.

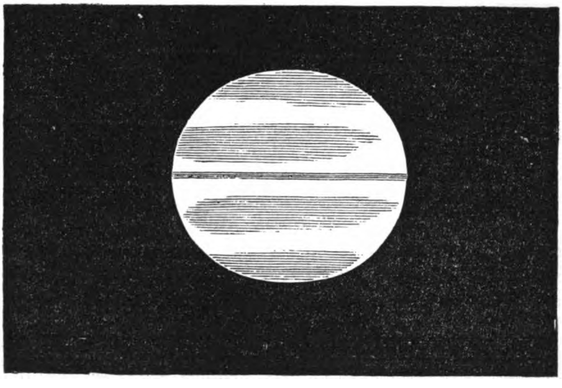

fig. 51. Saturn without his Ring; its shadow only visible.

Earth. Our remarks must be considered as applying to observations with telescopes in common use.

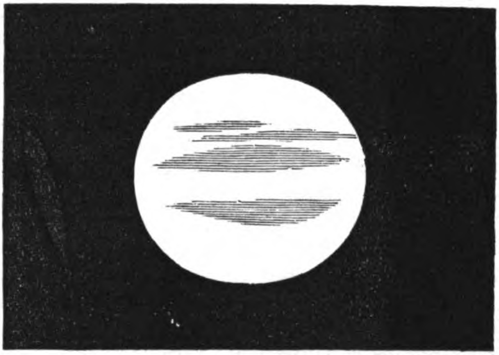

fig. 52. Saturn on Sept. 14, 1848, as viewed in a 6-feet telescope.

By watching several small luminous prominences upon the ring, Sir William Herschel ascertained that it rotates round the globe of Saturn in $10^h\ 32^m\ 15^s$, in the same direction as the planet revolves upon its axis. It has further been discovered by exact measurement, that the globe, or *ball* as it is generally termed, is not precisely in the centre of the rings, though so nearly concentric with them that the eye cannot readily perceive any deviation. The rotatory motion and slight excentricity of the rings are known to be essential for their stability, as otherwise they would be liable to collapse or fall upon the planet's surface.

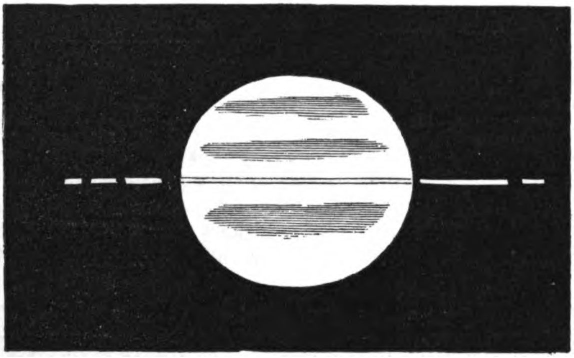

fig. 53. The Ring visible as a broken line.

When the rings are most open, the light reflected by them adds considerably to the brilliancy of Saturn. In these latitudes his lustre is greatest while he is traversing the sign Gemini, and almost places him on an equality of brightness with the fiery planet Mars.

The exterior edge of the outer ring is about 85,000 miles distant from the centre of the globe of Saturn, and the interior edge of the inner ring 57,000 miles from the same point, or 18,500 from the surface. The exterior ring is 10,000 miles broad, the interior one 16,500. The obscure ring lies, as before stated, within the nearest of the bright ones. It appears probable that the *thickness* of the rings does not exceed 100 or 150 miles at most.

Besides the rings, which must serve to reflect a great quantity of light upon his surface, Saturn is accompanied by eight satellites to illumine the darkness of his short nights. Their periods vary from $0^d\ 22\frac{1}{2}^h$ to $79^d\ 8^h$, and their mean distances are between 118,000 and 2,270,000 miles.* The *first* and *second*, reckoning from the primary, were discovered by Sir William Herschel; the former in 1789, the latter two years earlier: they are excessively minute objects, perceptible only in the largest telescopes we possess. The *third*, *fourth*, and *fifth*, were found by Cassini, a French astronomer, in 1672 and 1684; they are much brighter than the Herschelian satellites, but yet require pretty powerful telescopes to be distinctly seen. The *sixth*, discovered by Huyghens in 1655, is the largest and brightest of the eight, being little inferior to the planet Mars in size. The *seventh* was very recently discovered (in 1848) by Mr. Lassell, in England, and Professor Bond, in America; like the interior satellites, it is extremely difficult to observe. The *eighth* or exterior moon is next in magnitude to the *sixth*, and is tolerably conspicuous; its orbit is considerably inclined to Saturn's equator, and therefore to the plane of the rings, whereas the others revolve very nearly in that plane. By attentively noting the brightness of this satellite in its various positions with respect to Saturn, Sir W. Herschel discovered that it rotates on its axis in the same time that it completes a revolution round the primary, and this is supposed to be the case also with the other seven.

To obviate some confusion in the nomenclature of the satellites, Sir John Herschel has lately proposed for them the following names, beginning with the one which is nearest to Saturn: Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Japetus.

THE PLANET URANUS.

Uranus was discovered by Sir William Herschel on the 13th of March 1781, while he was occupied in a close examination of the small stars lying near the ecliptic. Having noticed one which seemed to have a sensible breadth, unlike other objects in its neighbourhood, Sir W. Herschel watched it attentively, and soon ascertained that it was in motion, though at a very slow rate. Some doubts existed for a short time after the discovery, as to the nature of this object, but in a few months it was acknowledged to be a new member of the planetary system, outside the orbit of Saturn, which had been previously considered the boundary of the same, and on the suggestion of Professor Bode, received the name *Uranus*. It has sometimes been called the *Georgium Sidus* or *Herschel*; the former being the designation proposed by the discoverer: these names, however, have now fallen into disuse.

The planet may be just discerned by a person gifted with strong sight, without the telescope, in a perfectly dark sky, if its exact position in reference to the surrounding stars be known to him. Since its movements were understood, astronomers have been able to shew that Uranus was observed by Flamsteed, the first director of our Royal Observatory, on several occasions between the years 1690 and 1715; by Mayer at Göttingen in 1756; and by Le Monnier at Paris, on twelve nights between 1760 and 1771; all of whom imagined it to be a fixed star. The honour of the discovery was therefore reserved for Sir William Herschel.

Uranus revolves round the Sun in 30,687 days, which is a little over

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* See the Synoptical Table of the Planetary System.

84 years, at a mean distance of 1,829 millions of miles. His mean velocity is 15,600 miles per hour, or 4⅓ in a second.

The apparent diameter of this planet never varies much from four seconds; yet were it separated from us by only the distance between the Earth and Sun, it would present a visible breadth twice as great as that of Jupiter. The real diameter is about 36,000 miles, and the solid contents or volume 96 times greater than the Earth's. The Sun's mass exceeds that of Uranus 21,000 times.

No telescopes hitherto constructed have succeeded in shewing any spots or belts upon this planet, owing to its enormous distance, and the consequent minuteness of its disc. The time of rotation, and the position of the axis with respect to the orbit, are for this reason unknown to us, and likely to remain so.*

Sir W. Herschel supposed he had seen six satellites to Uranus, and gave a table of their periods and distances from the primary, which, for want of more observations, were rather conjectured than inferred by direct calculation. More recently, four little moons have been satisfactorily observed with some of the large and powerful instruments in European

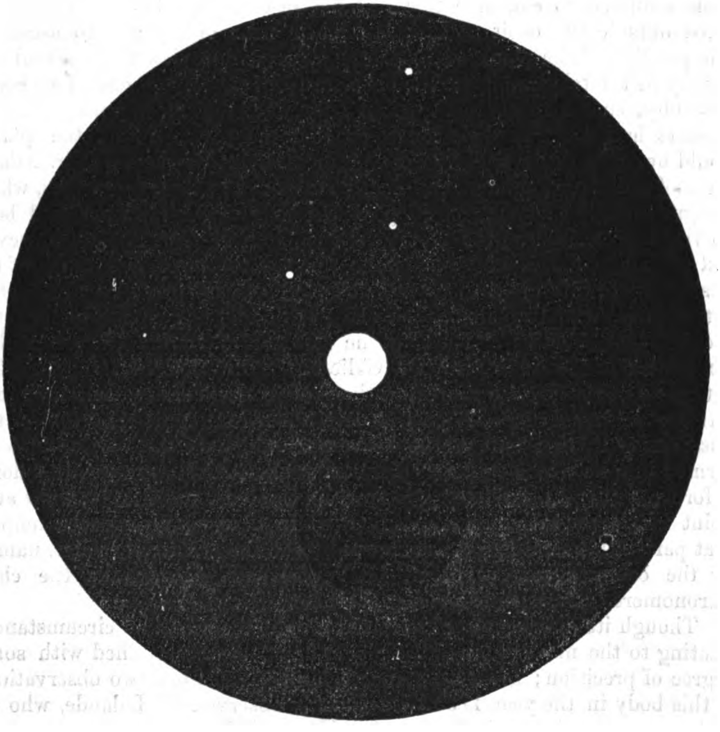

fig. 54. Uranus and his Satellites.

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* The length of rotation (9h 30m) sometimes given in popular works is purely conjectural, and does not rest on any sufficient foundation.

observatories.* The two interior satellites are far more difficult to see than the others, which are comparatively bright; but no telescopes of ordinary capacity will afford the slightest glimpse of any one of the four. It is a curious fact, that the course followed by the satellites of Uranus is *retrograde*, or contrary to that of the Earth in her orbit; the only instance of the kind in the planetary system.

THE PLANET NEPTUNE.

The discovery of the planet Neptune forms a memorable epoch in the history of astronomy, not only as affording a remarkable confirmation of the truth of the Newtonian laws of gravitation, but an equally striking proof of the advanced state of mathematical reasoning at the present time.

The circumstances attending this discovery were briefly as follows: It had been noticed for many years that the motion of Uranus was not exactly such as it was calculated it should be, after taking into account all known causes of disturbance. Two young mathematicians, M. Le Verrier of Paris, and Mr. Adams of Cambridge, England, were induced, unknown to each other, to inquire into the source of this apparent anomaly, and were soon led to conclude that a planet of considerable magnitude must exist outside the orbit of Uranus. Their next object was to ascertain the position of the planet amongst the stars, with a view to its actual discovery in the telescope; but the problem to be solved was one of excessive difficulty, so much so, in fact, that several of our most eminent astronomers had declared their conviction that the place of the latent planet could never be discovered by calculation. M. Le Verrier and Mr. Adams were of a different opinion, and finally succeeded in their researches, which assigned nearly the same position to the body whose influence had been so visibly exercised on the movements of Uranus. Mr. Adams, however, did not make his conclusions public through the press, and much of the first glory of this great discovery was consequently given to the French astronomer, who had announced the position of the new planet to the Academy of Sciences at Paris in the summer of 1846. On the 23d of September of the same year, Dr. Galle of the Royal Observatory, Berlin, acting upon the urgent representations of M. Le Verrier, contained in a letter which reached Berlin on this date, turned the large telescope of the observatory to that part of the heavens in which M. Le Verrier had informed him he would find the disturbing planet. Hardly was this done, before a pretty bright telescopic star appeared in the field of view at a point where no such object was marked in a carefully-prepared map of that part of the heavens. This proved to be the predicted planet, named by the common consent of M. Le Verrier, Mr. Adams, and the chief astronomers of Europe, the planet *Neptune*.

Though its discovery is of so recent a date, the principal circumstances relating to the movements of the planet have been ascertained with some degree of precision; great assistance being derived from two observations of this body in the year 1795 by a French observer, M. Lalande, who on both occasions mistook it for a star. The period of revolution is 60,127 days, or a little over 164½ years, which is twice the period of Uranus.

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* See the Synoptical Table of the Planetary System.

The mean distance of the planet from the Sun is no less than 2,864 millions of miles; upwards of 1000 millions beyond the path of Uranus!

The real diameter of Neptune is 35,000 miles; though at his enormous distance from the Earth it appears so small as to be scarcely of appreciable breadth without a first-rate telescope. His mass is about $\frac{1}{18000}$th part of the Sun's. In point of magnitude and attractive power we see that Uranus and Neptune are not very different.

One satellite, discovered by Mr. Lassell of Liverpool, is known to attend this planet. It revolves round the primary in $5^d\ 21^m$, at a distance of 230,000 miles.

Neptune is the farthest planet actually known to exist.

THE COMETS.

COMETS differ in so many respects from planets, that beyond the facts of their belonging to the same system, and obeying in their motions the same laws of gravitation, there is little analogy between them.

Comets are observed only in those parts of their orbits which are nearest to the Sun ; they are not confined, like the planets, to the zodiac, but appear in every quarter of the heavens, and move in every possible direction. They usually continue visible a few weeks or months, and very rarely so long as a year. Their appearance, with some few exceptions, is nebulous or cloud-like, whence it is inferred that they consist of masses of vapour, though in a highly attenuated state, since very small stars are often seen *through* them.

The more conspicuous comets are accompanied by a *tail,* or train of light, which sometimes stretches over an arc of the heavens of 50° or 70° or upwards, but more frequently is of much less extent.

It is necessary to draw some distinction between those great comets recorded in history as having created astonishment and terror from their brilliancy and magnitude, and that faint, filmy, but far more numerous class that can only be discerned with telescopes. The same body may assume very different appearances during its visibility, according to its position with respect to the Earth and Sun. When first perceptible, a comet resembles a little spot of faint light upon the dark ground of the sky ; as it approaches the Sun, its brightness increases, and the tail begins to shew itself. Generally the comet is brightest when it arrives near its perihelion, and gradually fades away on its recession from the Sun, until it becomes quite imperceptible with the best telescopes we possess.

Some few have become so intensely brilliant as to be seen in *full daylight.* A remarkable instance of this kind occurred in February 1843, when a comet was discovered in various parts of the world within a few degrees of the Sun himself, and there are one or two similar instances on record.

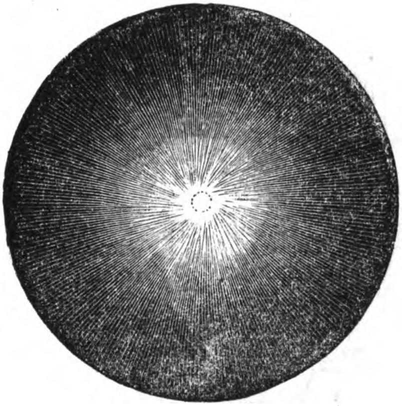

fig. 56. General appearance of telescopic Comets.

The brighter or more condensed part of a comet, from which the tail proceeds, is called the *nucleus ;* and the nebulous matter surrounding the nucleus is termed the *coma :* frequently the nucleus and coma are included under the general term *head.* Some comets have no nuclei, their light being nearly uniform.

The tail almost always extends in a direction opposite to that of the Sun at the time ; a fact first noticed by Apian in the sixteenth century. In some it is long and straight ; in others, curved near the extremity, or divided into two branches. A few have exhibited two distinct tails. The real length of this train has sometimes exceeded 100 or 150 millions of miles ; that of the great comet of 1843 is said to have been 200 millions of miles long.

It is supposed that the general form of the orbits of these bodies is a highly elongated or excentrical ellipse, a curve which is very difficult to manage in calculation.

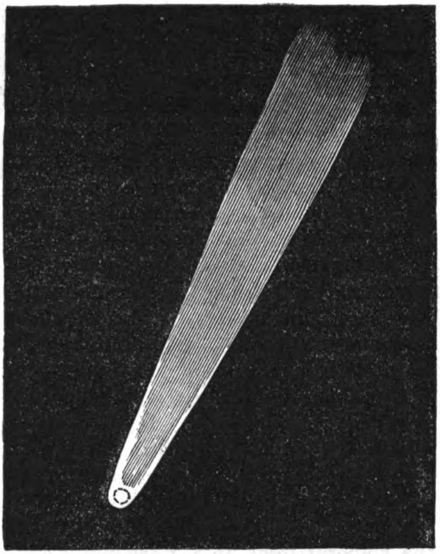

fig. 57. The Comet of Halley, 1835.

Astronomers have ascertained with great precision the periods which certain comets require to perform their revolutions round the Sun, and are able to predict the times of their becoming visible from the Earth, and the tracks they must follow amongst the stars. This was first done by Dr. Halley in the case of a comet observed in 1682, which he discovered was the same that had appeared in 1456, 1531, and 1607, and hence concluded that its revolution was accomplished in about seventy-five years. He foretold its reappearance in 1759, which actually took place after a retardation of between one and two years, through the attraction of Jupiter and Saturn. The same body was watched with great interest in 1835; and will again visit these parts of space about the year 1911. It may be traced in history as far back as the year 11 B.C.

A comet called *Encke's* has a period of 3⅓ years; another, Biela's, of 6¾ years; and several others perform their revolutions in from five to eight years.

There are some few comets, besides the one above mentioned, which complete their journey round the Sun in from sixty to eighty years; but it is certain that by far the greater number require hundreds or even thousands of years to perform their revolutions. When this is the case, it becomes almost impossible to assign their exact periods, the difficulty increasing as the times of revolution lengthen.

Remarkable comets appeared in 1680 and 1843, both of which approached so near to the Sun as almost to *graze his surface.* Another, in 1729, scarcely advanced within the orbit of Jupiter. The comet of 1811 has acquired great celebrity: it remained visible to the naked eye several months, shining with the lustre of the brighter stars, and attended by a beautiful fan-shaped tail; this body is supposed to require upwards of 3000 years to complete its excursion through space.

About the year 1858 a large comet is expected to make its appearance, after an absence of more than 300 years. It was last observed in 1556, and is believed to have been also visible in 1264, with a tail 100° long, to the great astonishment and alarm of our forefathers.

Probably there are many thousands of comets belonging to the solar system, of which a large proportion may never come sufficiently near the Sun to be seen from the Earth.

THE ZODIACAL LIGHT.

The zodiacal light, as seen in this country, is a faint luminosity of a lenticular or conical form, which makes its appearance above the western horizon in the spring, and the eastern horizon in the autumn, shortly after sunset, or before sunrise, that is, during the continuance of twilight. It stretches upwards nearly in the direction of the ecliptic: the average breadth at the base is about 20°; the vertex sometimes occupies a position 90° distant from the Sun's place at the time, but more commonly is not traced so far.

The true nature of this phenomenon is not yet understood. By some it has been regarded as a kind of nebulous envelope attending the Sun, and including within its boundaries the orbits of Mercury and Venus, if not that of the Earth.

In tropical climates the zodiacal light is much more conspicuous than in the temperate zone. Humboldt describes it as perpetual near the equator, whereas its visibility in this country is very irregular. In some years it may be observed almost every clear evening between January and April, in others it is only dimly seen early in March.

Our countryman Childrey first drew the attention of astronomers to the zodiacal light, in a work published about the year 1660. He considered it a new discovery; but there is strong reason for supposing that it was remarked many centuries prior to this date.

AEROLITES, FIRE-BALLS, AND SHOOTING-STARS.

THE PERIODICAL METEORS OF AUGUST AND NOVEMBER.

Aerolites, or *meteoric stones*, are extraneous bodies which occasionally fall upon the surface of the Earth. In their descent they usually exhibit an intensely brilliant light, and are accompanied by a report resembling the discharge of cannon. Large stones or fragments of stones have been picked up from time to time after occurrences of this nature; they are often deeply imbedded in the earth, which proves that they must have descended with prodigious force.

These bodies are now very generally considered to be fragments traversing the planetary spaces, and at times drawn by the Earth's attraction to her surface. A chemical analysis of their contents strongly favours the supposition of their being of foreign, or, so to speak, astronomical origin.

In two or three instances attempts have been made to ascertain the kind of path followed by aerolites. Their absolute velocities in space are found to exceed even the rate at which the Earth travels in her orbit. An aerolite which traversed France on the 6th of July 1850, was computed to be moving with a velocity of more than forty miles per second. Such results, however, are liable to great uncertainty, because the appearance of the meteor is very sudden, and of course unexpected, so that it is difficult to procure satisfactory data upon which to calculate.

It is quite possible that, under certain conditions, an aerolite might become, for a time at least, a satellite of the Earth.

Shooting-stars are those evanescent meteors which dart across the sky at night in all directions, and generally leave behind them luminous trains visible some seconds after the extinction of the brighter part. *Fire-balls* are a larger and more brilliant kind of meteor, far less frequently observed than the shooting-stars, which may be seen almost every clear night. Many of these objects would appear to be merely of atmospheric origin, since they are usually numerous in certain states of the weather, especially in clear intervals after showers of rain, with a strong wind blowing at the time. A singular regularity or periodicity has been remarked in the recurrence of the greater exhibitions of shooting-stars, which has induced some astronomers to regard them as bodies of a cosmical nature circulating in the planetary spaces, and ignited, or at least rendered visible, by their passing through the Earth's atmosphere. It has been noticed that about August 10th and November 13th such meteors have appeared for many years together in extraordinary abundance, and, with comparatively few exceptions, affect particular points of divergence in the heavens, as they should appear to do if they be really extraneous bodies encountered by the Earth in the course of her revolution round the Sun.

In order to explain the occurrence of meteoric showers on the same days of the month for several consecutive years, it is obviously necessary to suppose that great numbers of meteoric bodies are revolving about the Sun in periods equal to that of the Earth, and in orbits which intersect or meet our own in the regions of the ecliptic through which we pass on those days.

In addition to the fact of their diverging from certain fixed points amongst the stars, the velocities of the periodical meteors of August and November, which average from ten to twenty miles per second, are regarded as strongly favouring their foreign origin.

THE FIXED STARS.

OF THE STARS GENERALLY. NUMBER VISIBLE TO THE NAKED EYE. TELESCOPIC STARS.

THOSE glittering points of light so profusely scattered over the sky in all directions, which are included under the general term of *fixed stars*, are believed by astronomers to be suns like our own, which afford light and heat to other systems of worlds circulating round them. They must be self-luminous, for no light reflected from our Sun could render them visible at the enormous and almost inconceivable distances at which they are situated in respect to the solar system.

Though termed *fixed* stars, it may be doubted whether there is really, in the strict sense of the word, a fixed star in the heavens. The term is used comparatively, to distinguish them from the planets, which are continually changing their places. And further, the term will apply very correctly to the stars as they appear to the naked eye; for it is probable there has been no sensible change in the configuration of the heavens so viewed during the past 2000 years. The telescope is required to detect those small movements which most of the stars possess, and which will be explained in the sequel.

The discs presented by the stars, under telescopic examination, are not real but spurious ones, arising from the dispersion of light in passing through the Earth's atmosphere. The actual *size* of any star is not known.

The scintillation or twinkling of the stars, which contrasts so strongly with the steady light of the principal planets, is an optical phenomenon supposed to be due to what is termed the *interference of light.* Humboldt, the celebrated traveller, states that in the pure air of Cumana, in South America, the stars do not twinkle after they attain an elevation, on the average, of 15° above the horizon.

The actual number of stars visible to the naked eye at the same time, on a clear dark night, is between 2000 and 3000, though a person forming an estimate of their number from casual observation is almost certain to make it very much larger. It is a well-ascertained fact that, *in the whole heavens*, the stars which can be distinctly seen without the telescope, by any one gifted with good sight, do not exceed 6000.

The telescopic stars are innumerable. It has been conjectured that more than *twenty millions* might be seen with one of the Herschelian twenty-feet reflectors; and if we could greatly increase the power of our telescopes, there is no doubt that the number actually discernible would be vastly augmented.

CLASSIFICATION IN MAGNITUDES.

The stars are divided, according to their degrees of brightness, into separate classes, called *magnitudes.* The most conspicuous are termed stars of the *first* magnitude: there are about 22 so classed. The next in order of intensity of light are stars of the *second* magnitude, which amount to about 50 or 60 in number. Of the third magnitude there are 200 or upwards, and many more of the fourth, fifth, and sixth. These six classes comprise all the stars that can be well seen with the naked eye on a clear night. Telescopes in common use will shew fainter stars to the *tenth* magnitude inclusive, while the powerful instruments in observatories reveal an almost infinite multitude of others, even down to what have been considered eighteenth or twentieth magnitudes.

This arrangement of the stars, especially of the telescopic ones, is purely arbitrary, so that it is not unusual to find astronomers differing greatly in their estimates of brightness.

THE CONSTELLATIONS.

For the sake of more readily distinguishing the stars, and referring to any particular quarter of the heavens, they have been divided or arranged into groups called *constellations*, each one having some special figure to which the configuration of its stars may be supposed to bear a resemblance. Many are figures of birds and animals; the classical heroes, &c. of antiquity have also been brought into requisition.

This fanciful mode of grouping the stars is of very ancient date, but has been continued by modern astronomers chiefly for the sake of avoiding the confusion that might arise from an alteration in the old system, and not on account of any peculiar advantages which it possesses.

There are twelve constellations lying upon the zodiac, and hence called the *zodiacal constellations*, viz. Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces. These are also the names of the twelve divisions of 30° each into which the ecliptic was formerly divided; but the effect of precession, which throws back the place of the equinox amongst the stars from year to year, prevents a constant agreement between the directions of these twelve constellations and the corresponding signs.

The principal constellations in the northern half of the heavens, in addition to such of the zodiacal ones as lie north of the celestial equator, are:

Andromeda,
Aquila,
Auriga,
Bootes,
Cassiopeia,
Cepheus,
Corona Borealis,
Cygnus,
Draco,
Hercules,
Lyra,
Pegasus,
Perseus,
Ursa Major,
Ursa Minor.

The principal constellations situated on the south side of the equator, exclusive of the six southern zodiacal ones, are:

Argo Navis,
Canis Major,
Canis Minor,
Centaurus,
Cetus,
Crux,
Eridanus,
Monoceros (chiefly south),
Ophiuchus,
Orion,
Piscis Australis.

Others will be found upon celestial globes and charts, raising the total number of constellations at present recognised by astronomers to about eighty.

It should be remarked that, with some few exceptions, it is difficult to trace any similarity between the configuration of the stars and the figure within which they are included. Ursa Major, however, has some little resemblance to a bear; Leo to a lion; Corona Borealis to a crown; and the bright stars of Scorpio to the body and tail of a scorpion.

METHODS OF DISTINGUISHING THE STARS FROM EACH OTHER.

STAR CATALOGUES.

Many of the brighter stars had proper names assigned to them at a very early date, as *Sirius*, *Arcturus*, *Rigel*, *Aldebaran*, &c., and by these names they are still commonly distinguished.

It was the custom in former times to indicate the locality of a star by its position in the constellation to which it belonged—thus Aldebaran was called *Oculus Tauri*, Rigel *Orionis pes lucidus*, and so on; but as the science progressed, this method was found to be extremely tedious and troublesome, besides being frequently liable to misconception. Bayer, a German astronomer, was the first to improve upon the old plan by publishing, in 1604, a series of maps of the heavens, in which the stars of each constellation were distinguished by the letters of the Greek and Roman alphabets, the brightest being usually called α, the next β, and so on, though there are exceptions to this rule. Bayer's letters are yet in common use amongst astronomers, who add the Latin name of the constellation to which a star appertains in the genitive case: thus, Aldebaran is termed α Tauri; Rigel, β Orionis; Sirius, α Canis Majoris. Flamsteed, the first Astronomer Royal at Greenwich, affixed numbers to the different stars he observed, which are also much used at the present day.

Catalogues of stars have been formed at various times, in which are indicated their right ascensions and declinations for a certain epoch. Hipparchus is believed to have been the first who undertook such a compilation: his catalogue included rather more than 1000 stars, and has been preserved to us in the *Almagest* of Claudius Ptolemy. Some modern catalogues contain 20,000 or 30,000 stars, and in one instance as many as 47,000; yet, taking them altogether, the tabulated or catalogued stars are not more than 130,000, which, large as it may appear, is but a small proportion of the number visible with a good telescope.

It is usual to arrange the stars in the order of their right ascensions at the epoch of the catalogue, attaching numbers for convenience of reference.

REMARKABLE GROUPS OF STARS.

AMONGST the most conspicuous groups of stars in the northern hemisphere are the seven bright ones in Ursa Major, popularly known as *Charles's Wain*, or the *Butcher's Cleaver*. They form the outstretched tail and hinder part of the body of the Great Bear. They are in the north at midnight about the end of September, and nearly vertical in London at the same hour towards the end of March; but as all the seven stars are

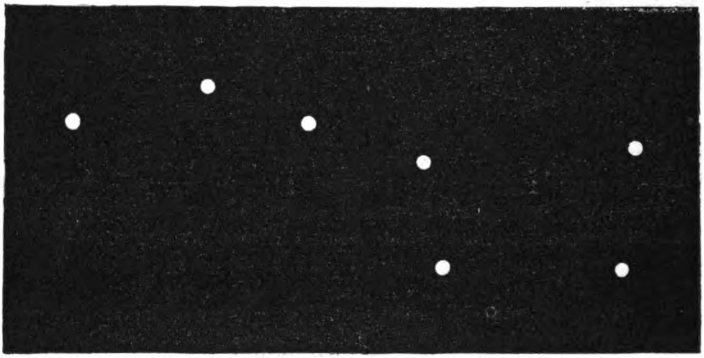

fig. 58. The Seven bright Stars in Ursa Major (Charles's Wain).

distant from the pole by a less number of degrees than are contained in the latitude of the place, they never descend below the horizon, and are consequently to be seen at all hours and at all times of the year in some part of the northern half of the heavens. Two of the stars in this group (α and β Ursæ Majoris) have received the name of *the Pointers*, because a line drawn through them and extended some distance, passes very near to the pole of the equator, and within a few degrees from Polaris or the North Pole star, which they afford an easy means of identifying.

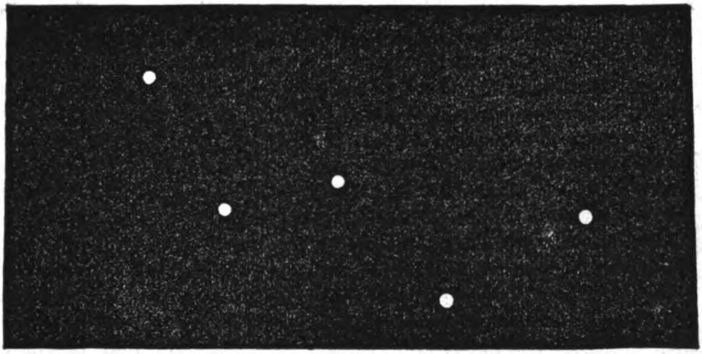

fig. 59. Cassiopeia.

Cassiopeia, another constellation which never sets in England, presents five stars in the form of a W. It is in the north between the Pole-star and the horizon at 10 o'clock in the evening early in April, and not far from the zenith at the same hour about the beginning of October.

An equally conspicuous, and far more beautiful assemblage of stars is presented in the constellation *Orion*, which lies chiefly below

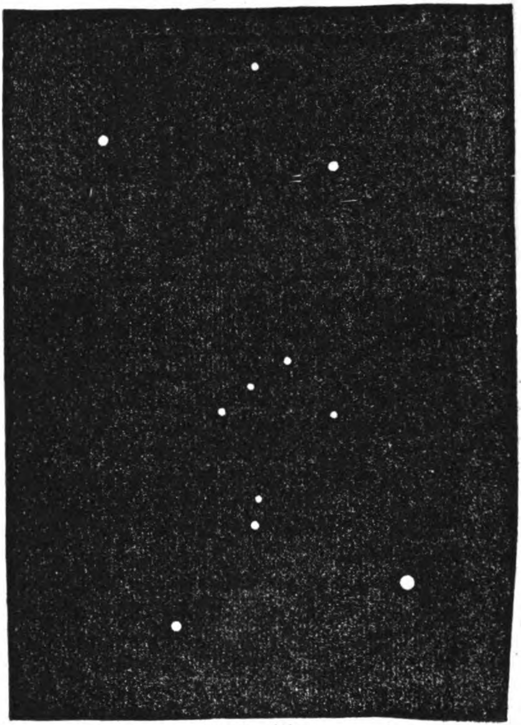

fig. 60. Orion.

the celestial equator. It is in the south at midnight in the middle of December, and at 10 o'clock in the evening a month later, when it is easily recognised by the three stars in the belt of the giant, situate as in the figure. To the left of Orion, and a little below it, is then seen the star Sirius, which far surpasses all others in brilliancy.

The *Square of Pegasus* is formed by four moderately bright stars, which appear at a considerable altitude above the horizon in the southern quarter of the sky about 10 in the evening in the middle of October.

The *Pleiades* are a clustering group of stars above the constellation Orion. The naked eye discerns seven or eight, but in the telescope upwards of two hundred are revealed.

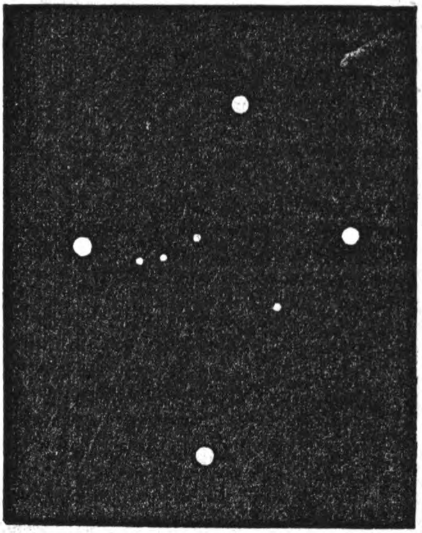
Fig. 61. The Southern Cross.

A little below, and to the left of the Pleiades, is a wedge of stars called the *Hyades*, of which Aldebaran is the conspicuous member.

In the southern heavens there is a beautiful group of stars called the *Southern Cross*, consisting of four bright ones and others of less magnitude. It was visible in England 4000 years ago; but the effect of precession since this remote period has brought it so much nearer to the southern celestial pole, that at the present time it never appears above our horizon.

A practical knowledge of the constellations generally is best acquired by the help of a globe, or a series of charts, which the young astronomer should compare with the heavens.

THE POLE-STAR NOT ALWAYS THE SAME.

The star of the third magnitude (α) in Ursa Minor, which, from its proximity to the north pole of the equator, is called *Polaris* or the *Pole-star*, has not always occupied the prominent position it does at present. In the days of Hipparchus it was 12° from the pole, whereas its distance is now less than 1½°, and will diminish until it comes within ½°; the star must then recede from the pole, and give place to another claimant for the honour of being our polar star.

Four thousand years before the Christian era, when the pyramids of Gizeh are supposed to have been erected, α Draconis was the nearest conspicuous star to the north pole. In twelve thousand years from the present date the bright star Vega in Lyra will approach within 5° from the same. These changes arise from the revolution of the pole of the equator round that of the ecliptic in the lapse of about 26,000 years.

The south pole is not marked by the presence of so bright a star as the opposite one. It falls in the constellation Octans near *σ*, a star of the sixth magnitude only.

DISTANCE OF THE FIXED STARS.

The distance of the stars is a subject which has naturally engaged the close attention of astronomers, ancient and modern; but all their efforts to arrive at any thing like a satisfactory conclusion have failed until within a very recent period. In treating of parallax, it has been stated that the stars appear in precisely the same positions from whatever part of the Earth they are viewed, and that with the hope of detecting some change of place by which to judge of their separation from us, they have been observed at points as widely distant from each other as we are able to command, viz. from opposite parts of the Earth's annual orbit. With this base-line of 190 millions of miles, there is the most favourable chance of detecting the parallax of a star, provided the instruments employed are sufficiently accurate.

An annual parallax of *one second* of arc would indicate a distance of about 206,000 times the radius of the Earth's orbit, that is, of 206,000 times 95 millions of miles. In only one instance has a parallax closely approaching this amount been discovered, and this is in the case of the star *α* Centauri, which is never visible in England. It is found that the semi-diameter of the Earth's orbit would subtend at the star an angle of $\frac{97}{100}$ths of a second, whence it follows that the distance must be 211,000 times the distance of the Sun from the Earth, or *twenty billions* of miles. The late Professor Henderson, Astronomer Royal at Edinburgh, and formerly at the Cape of Good Hope, has the merit of having first detected the parallax of *α* Centauri.

This distance is so enormous that the mind is hardly able to appreciate it; light, with its astounding velocity of 191,500 miles per second, furnishes the only unit by which it can be measured and brought within small numbers. Suppose a ray to leave this star, travelling through space at the above prodigious rate, it would not reach the Earth until after the expiration of 1218 days or 3⅓ years. We do not see the star as it actually is, but it shines with the light emitted 3⅓ years ago. Hence if it were obliterated from the heavens, we should continue to see it for more than three years after its destruction!

Shortly before Professor Henderson's announcement appeared respecting *α* Centauri, the great astronomer Bessel of Königsberg had published the results of his observations upon a star of the sixth magnitude, numbered 61 in Cygnus, from which it was inferred to have a parallax of $\frac{37}{100}$ths of a second; a conclusion fully confirmed by the late researches of Dr. Peters, a Russian observer and mathematician. Its distance must be 550,900 times that between the Earth and Sun, or 52 billions of miles —a space which light would not traverse in less than 8⅔ years.

Another star in the constellation Ursa Major,* invisible to the naked eye, exhibits a parallax of ¼ of a second; and several others have had smaller parallaxes assigned to them. Sirius, the brightest star in the

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* Generally known as No. 1830 of Groombridge's Catalogue of Stars, and frequently termed *Argelander's star.*

heavens, shews a parallactic displacement of a quarter of a second, which indicates a distance greater than that of 61 Cygni, a star of the sixth magnitude only. Vega in Lyra is supposed to have a parallax of about the same amount. In the present state of our knowledge, it would appear that the *brightest* stars are not always the *nearest* to the solar system.

It has been considered probable, from recondite investigations, that the average distance of a star of the *first* magnitude from the Earth is 986,000 radii of our annual orbit, a distance which light would require 15½ years to traverse: and further, that the average distance of a star of the *sixth* magnitude (the smallest distinctly seen without a telescope) is 7,600,000 times the same unit; to traverse which, light, with its prodigious velocity, would occupy more than 120 years. If, then, the distances of the majority of stars visible to the naked eye are so enormously great, how are we to estimate our distance from those minute points of light discernible only in powerful telescopes? The conclusion is forced upon us that we do not see them as they appeared within a few years, or even during the life-time of man, but with the rays which proceeded from them several thousands of years ago! What an idea does this consideration give us of the immensity of the stellar universe!

PROPER MOTIONS OF THE STARS.

The changes in the positions of the stars due to aberration and nutation are merely apparent movements, and their exact amounts can be readily calculated for every star. The effects of precession can be determined with equal facility.

It is found by observation, however, that most stars exhibit a slow motion in the heavens which cannot be thus accounted for; after due allowance has been made for precession, aberration, and nutation, there still remain very appreciable changes of position. These are not such periodical motions to and fro as would be produced by parallax; on the contrary, they are uniformly progressive from year to year.

There are two ways in which such movements may be explained in the case of an *individual star*. Either the star itself may be supposed to have a real motion through space to the observed amount, or the Sun, the Earth, and all the other planets may have a similar real motion in a contrary direction to that of the star's apparent one. On extending the inquiry to a greater number of stars, it appears beyond doubt that both causes must be in existence, certain stars having really an independent motion in the heavens, which, to distinguish it from merely apparent displacements, is termed the *proper motion*, while the solar system itself *travels through space.*

Although the observations of modern astronomers shew that a great number of stars exhibit proper motions, there are some few that have especially attracted attention from the rapidity with which they appear to be journeying as compared to the rest. 61 Cygni, one of the stars already mentioned as within measurable distance, is moving at the rate of more than five seconds annually; and the star in Ursa Major, to which reference has also been made, travels at the rate of seven seconds in a year. The parallaxes, and hence the distances of both stars, are presumed to be approximately known; but we are ignorant of the *real directions* of their proper motions in the heavens, and therefore cannot assign the exact velocities at which they are travelling: they may be moving either towards us or from us, and their real change of place in a certain interval being thus foreshortened, the apparent movements would be very much less than the true ones. Still, if we suppose that the real direction of their proper motions is perpendicular to our line of vision, we can attach a velocity to each star *less* than which the true one *cannot* be; and thus it is computed that 61 Cygni is flying onward through space at the rate of *forty miles in a second*, and the star in Ursa Major at the rate of thirty miles in the same time. Yet at their vast distances from us, these almost inconceivable velocities of motion have only altered the apparent places of the stars in the heavens, since the commencement of the Christian era, the former by 2° 38′, and the latter by 3° 35′.

MOTION OF THE SOLAR SYSTEM THROUGH SPACE.

Sir William Herschel was the first to remark, in the proper motions of the stars generally, a decided tendency to diverge in one direction, and to draw together in the opposite quarter of the heavens. This he considered to arise from the translation of the solar system through space towards that part in which the stars appeared to be opening out; for the divergence of the stars from one point must necessarily follow if our Sun were in rapid motion *towards* the same, while the stars in the opposite part of the heavens would as certainly appear to be closing in, as the Sun receded from them. He concluded that the direction of the Sun's motion was towards a point in the constellation Hercules, not far from the star marked λ. More recent and extensive investigations have not only established the fact of the solar motion, but likewise indicated a direction very nearly coincident with that assigned by the above astronomer. The point now fixed upon is also in the constellation Hercules, in right ascension 261°, and 37° north of the equator.

The accompanying figures shew the effects of the Sun's motion in space

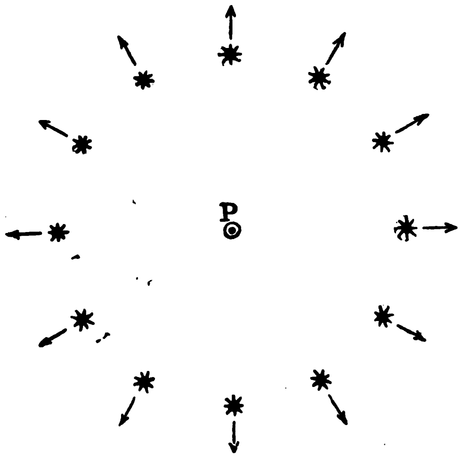

fig. 62.

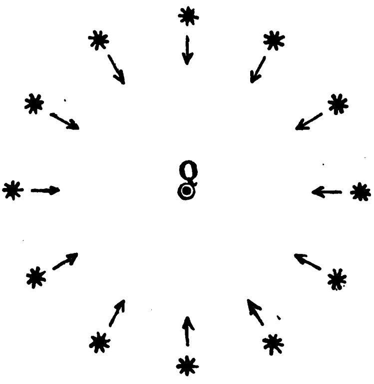

fig. 63.

upon the stars; P being the point towards which he is advancing, and Q that from which he recedes: the arrows indicate the direction of the apparent movements of the stars in the vicinities of these points.

It has been calculated that the Sun, and of course the planets attending him, are carried along at the rate of 150 millions of miles in a year, or 49 miles in a second! Though these numbers are not yet definitely established, they may be regarded as approximations to the true ones.

In the course of ages our system may so far change its situation in space, that the stars which now shine with the greatest brilliancy may dwindle to almost invisible points, and others yet scarcely perceptible may occupy their places in the heavens. But the time that must elapse before any change of this nature could be brought about is only to be reckoned by *millions of years.*

DOUBLE, TRIPLE, AND MULTIPLE STARS.

Many of the stars which appear single to the naked eye are found, on telescopic examination, to be *double*, or to consist of two stars very near each other. There are some thousands of such objects in the heavens.

In a few cases three stars are so situated as to form a *triple* star; and there are also combinations of four, five, or more stars, lying within small distances from each other, thus forming *quadruple*, *quintuple*, and *multiple* stars.

If two stars lie very nearly in the same line of vision, though one may be vastly more distant than the other, they will form an *optical* double star, or one whose components are only apparently connected by the near coincidence of their directions as viewed from the Earth.

The chances, however, are greatly against there being a large number of stars thus optically joined together. Sir W. Herschel was the first to discover that, in many cases, the two stars composing a double star have a real connexion, manifested by the motion of one star round the other. These are termed *physical* double stars, or binary systems, and in course of time will probably be found far more numerous than the class of merely optical double stars, whereof the components always retain the same relative position. As it is, astronomers have detected a revolving motion in a considerable number of objects, and by following up their observations from year to year have approximated to the periods in which the stars revolve about each other. Their orbits are elliptical, of various degrees of excentricity, and their movements are generally supposed to be governed by the Newtonian law of gravitation, though some authorities have hardly as yet acquiesced in the conclusiveness of the evidence to that effect.

In some instances the components of a double star are of equal brilliancy, but it more frequently happens that one star is brighter than the other. Occasionally the inequality of light is so great that the smaller star is almost lost in the refulgence of its brighter neighbour.

In several cases the periods of binary stars are less than a century; yet it is easy to see that, in the vast majority of these systems, the revolution of one star about the other must extend to hundreds or even to thousands of years.

The most rapidly revolving double star hitherto discovered is ζ Herculis, which to the naked eye shines like a star of the third magnitude:

the little companion travels round the large star in 36 years. The following have also comparatively short revolutions :

ζ Cancri	58½ years.
ξ Ursæ Majoris	61 „
η Coronæ Borealis	66 „
α Centauri	78 „
70 Ophiuchi	92 „

The fine star Castor in the zodiacal constellation Gemini, on being telescopically examined with a high power, is found to consist of two nearly equal components. Since the year 1719 their relative positions have greatly altered (as will be seen from the figure annexed) ; it is computed that a whole revolution of these stars about their common centre of gravity will be accomplished in about 550 years.

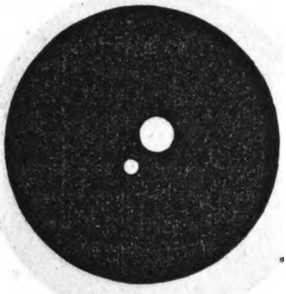

fig. 64. ζ Herculis.

fig. 65. Castor.

γ in Virgo is a very remarkable specimen of a binary system. The various positions of the two stars with respect to each other, since the

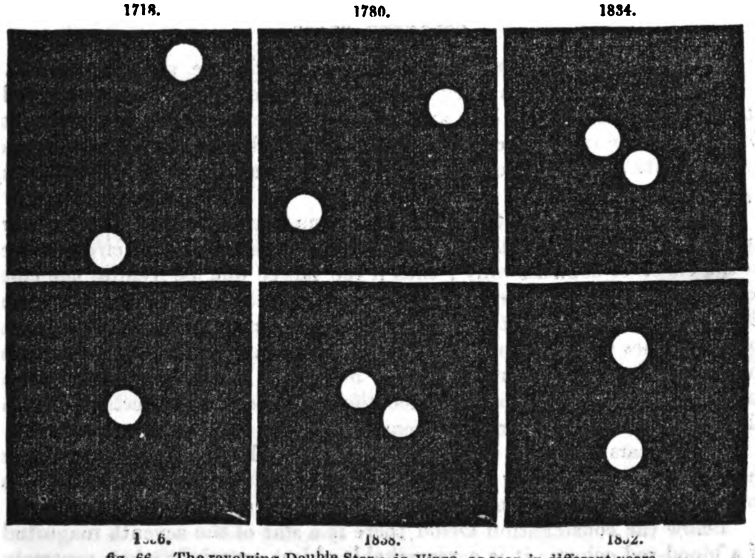

fig. 66. The revolving Double Star γ in Virgo, as seen in different years.

earliest observations, are shewn in the accompanying diagram. In 1836 they had approached so close together that no telescope could exhibit any separation. Now they have opened again, and will continue to widen their distance for many years to come. The period of revolution is presumed to be about 174 years.

Amongst the *triple* stars may be instanced ζ Cancri and 11 Monocerotis. In the former case it appears certain that while the two close stars revolve round each other in 58½ years, they, with the distant one, revolve also about a common centre of gravity in a much longer interval of time.

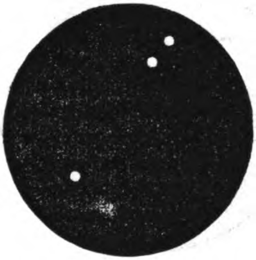

fig. 67. The Triple Star ζ in Cancer.

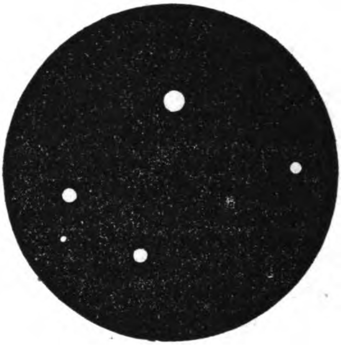

fig. 68. The Quintuple Star θ in Orion.

ε Lyræ furnishes an instance of a *quadruple* star, in which all the components are believed to be physically connected. θ Orionis in a powerful telescope is seen *quintuple*.

COLOURED STARS.

Many stars shine with a coloured light, as red, blue, green, or yellow.

These colours are exhibited in striking contrast in many of the double stars. Combinations of blue and yellow, or green and yellow, are not infrequent, while in fewer cases we find one star white and the other purple, or one white and the other red. In several instances each star has a rosy light.

When the complimentary colours are remarked in a double star, where one star is much smaller than the other, we may attribute the circumstance to the effect of contrast only; thus if the larger one be yellow, the companion may incline to blue; or if the former have a greenish light, the latter may be tinged with crimson. Yet it can hardly be doubted that in many cases the light of the stars is actually of different colours; that there exist in the universe numbers of yellow, blue, green, and crimson suns whose refulgence must produce the most beautiful effects upon the planets which circulate around them.

Single stars of a fiery red or deep orange colour are not uncommon, but there is no instance of an isolated deep blue or green star; these colours are apparently confined to the compound stars.

Below the constellation Orion there is a star of the seventh magnitude of a blood-red colour; it is a remarkable object, especially when contrasted with another star near it of similar brightness, but presenting a pure white light.

The following are a few of the most interesting coloured double stars.

Name of Star.	Colour of larger one.	Colour of smaller one.
γ Andromedæ	Orange	Sea-green.
α Piscium	Pale green	Blue.
β Cygni	Yellow	Sapphire-blue.
η Cassiopeæ	Yellow	Purple.
σ Cassiopeæ	Greenish	Fine blue.
ζ Coronæ	White	Light purple.
A star in Argo	Pale rose	Greenish-blue.
A star in Centaurus	Scarlet	Scarlet.

VARIABLE STARS.

There are many stars, not only amongst those visible to the naked eye, but also belonging to telescopic classes, which exhibit periodical changes of brilliancy; they have hence been called *variable* stars.

At present little or nothing is known respecting the cause of their regular increase and decrease. It has, however, been conjectured that dark opaque bodies may revolve about them, and at certain times intercept a portion of their light; or, that the stars themselves are not uniformly luminous all over their surfaces, but occasionally, from their axial rotations, present towards the Earth a disc partially covered with dark spots, thereby shining with a dimmer light. It is certain that these variations are entirely independent of any effect which the Earth's atmosphere could produce.

Algol, or β in the constellation Perseus, is one of the most interesting of the changing stars. For about $2^d\ 13^h$, it shines as an ordinary star of the second magnitude, and is therefore conspicuously visible to the naked eye. In somewhat less than four hours it diminishes to the fourth magnitude, and thus remains about twenty minutes; it then as rapidly increases to the second, and continues so for another period of $2^d\ 13^h$, after which similar changes recur. The exact period in which all these variations are performed is $2^d\ 20^h\ 48^m\ 55^s$.

Another remarkable object is the star *o* in Cetus, often termed *Mira*, or the *wonderful* star. It goes through all its changes in 334 days, but exhibits some curious irregularities. When brightest it usually shines as a star of the second magnitude, yet on certain occasions has not appeared higher than the fourth. Between five and six months afterwards it disappears altogether. Sometimes it will shine thus without perceptible change of brightness for a whole month; at others there is a very sensible alteration in a few days. The variability of Mira Ceti was discovered in the seventeenth century.

The list of changeable stars visible to the naked eye is pretty numerous; a few are here enumerated, with their periods of variation.

δ Cephei, which goes through its changes in			5 d. 9 h.
η Aquilæ,	„	„	7 4
α Herculis,	„	„	66 days.
A star in Aquila	„	„	72 „
A star in Corona Borealis,		„	323 „
A star near χ Cygni,	„	„	406 „
30 Hydræ,	„	„	495 „

In some cases the periods extend to many years. 34 Cygni, a star whose fluctuations were noticed as long since as 1600, is supposed to complete its cycle of changes in about 18 years.

The bright star Capella in the constellation Auriga is believed to have increased in lustre during the present century, while within the same period one of the seven bright stars (δ) in Ursa Major forming *Charles's Wain,* has probably diminished. Numerous instances of a similar kind might be mentioned.

IRREGULAR OR TEMPORARY STARS.

In the present state of our knowledge, it appears necessary to distinguish between the variable stars, properly so called, which go through their fluctuations of light with some degree of regularity, and are either always visible or seen at short intervals, and those wonderful objects that have occasionally burst forth in the heavens with a brilliancy in some instances far surpassing the light of stars of the first magnitude, or even the lustre of Jupiter and Venus, remaining thus for a short time, and then gradually fading away. To this class has been assigned the distinctive appellation of *irregular* or *temporary* stars.

The most celebrated star of the kind recorded in history is one which made its appearance in 1572, and attracted the attention of Tycho Brahe the Danish astronomer, who has left us a particular description of the various changes it underwent while it continued within view. It was situated in Cassiopeia, one of the circumpolar constellations, was first seen early in the autumn of 1572, and afterwards dwindled down until it became so faint in March 1574, that Tycho could no longer perceive it. During the early part of its apparition it far surpassed Sirius, and even Jupiter, in brilliancy, and could only be compared to the planet Venus when she is in her most favourable position with respect to the Earth. Persons with keen sight could see the star at noon-day, and at night it was discernible through clouds that obscured every other object. It twinkled more than the ordinary fixed stars; was first white, then yellow, and finally very red.

Another temporary star became suddenly visible in Ophiuchus, in 1604, and was observed by the famous Kepler. Though somewhat inferior to Venus, it exceeded Jupiter and Saturn in splendour. Like Tycho's star, it twinkled far more than its neighbours, but was not characterised by successive changes of colour: when clear from the vapours prevalent about the horizon, it was always white. This object remained visible till March 1606, and then disappeared.

Other stars, evidently of the same class, are mentioned by historians in remote times. One of a less conspicuous character was discovered by Anthelme, in 1670, not far from β Cygni; and another in April 1848, in the constellation Ophiuchus, which rose to the fourth magnitude, and has now faded away to the eleventh or twelfth, so that it cannot be seen without a good telescope. This is the last instance of the kind, and the only one since the year 1670.

THE VIA LACTEA, OR MILKY WAY.

The Via Lactea, Galaxy, or Milky Way, as it is variously termed, is that whitish luminous band of irregular form which is seen on a dark night stretching across the expanse of heaven from one side of the horizon to the other.

To the naked eye it presents merely a diffused milky light, stronger in some parts than in others; but when examined in a powerful telescope it is found to consist of myriads of stars, of millions upon millions of suns, so crowded together that their united light only reaches the unassisted eye.

The general course of the Milky Way is in a great circle, inclined about 63° to the celestial equator, and intersecting it in right ascension $0^h\ 47^m$ and $12^h\ 47^m$, or in the constellations Cetus and Virgo.

The distribution of the telescopic stars within its limits is far from uniform. In some regions several thousands (nay as many as are seen by the naked eye on a clear night over the whole firmament) are crowded together within the space of one square degree; in others a few glittering points only are scattered upon the black ground of the heavens. It presents in some parts a bright glow of light to the naked eye, from the closeness of the constituent stars; in others there are dark spaces with scarcely a single star upon them. A remarkable instance of the kind occurs in the broad stream of the Via Lactea, near the Southern Cross, where its luminosity is very considerable; but there exists in the midst of it a dark oval or pear-shaped vacancy, distinguished by the early navigators under the name of *the Coal-Sack*. When contrasted with the rich stelliferous region of the Milky Way in its neighbourhood, it is described as conveying a strong impression that, in viewing it, a person is looking into space, beyond the limits of this zone, through a comparatively starless opening. Similar vacancies occur in the constellations Scorpio and Ophiuchus.

From the results of a numerical estimate of the stars at various distances from the circle of the Via Lactea, by a process of counting which Sir William Herschel termed *gauging*, it has been proved that the stars are fewest in number near the poles of that circle, and increase—slowly at first, afterwards more rapidly—until we arrive at the Milky Way itself, where their number is greatest. The proportion of stars in this zone to the number at its poles is at least as 30 to 1.

Hence it is inferred that the stars which cover our heavens are not uniformly distributed throughout space, but, as described by Sir John Herschel, "form a stratum, of which the thickness is small in comparison with its length and breadth." The solar system would appear to be placed somewhat to the northern side of the middle of its thickness, since the density of the stars is rather greater to the south than to the north of the plane of the Via Lactea. From these and other considerations founded upon the relative distribution of the stars in various quarters of the heavens, Sir William Herschel was led to regard our starry firmament as possessing in reality a figure of which the annexed illustration will convey some idea, one portion being subdivided into two branches slightly inclined to each other.

The Earth being placed at S (not far from the point of divergence of the two streams), the stars in the direction of B and C would appear comparatively few in number, but would increase rapidly as the line of vision approached A, D, or E, in which directions we should see them most densely crowded; the rate of transition from the poorer regions to those offering an innumerable multitude of stars being such as we have alluded to above.

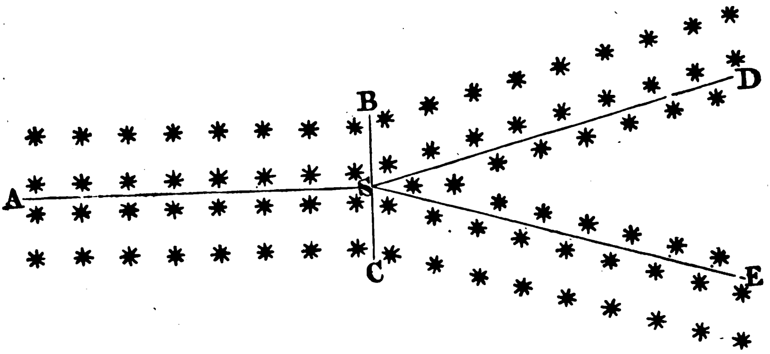

fig. 69.

Near the intersection of the streams D and E, few stars would present themselves, and there would consequently be a dark space, or rather a space thinly covered with stars, included within the two branches of the Milky Way. This exactly represents the actual appearance of the heavens: the luminosity of the Milky Way does separate into two distinct streams of light, which remain thus over an arc of about 150°, and then unite again.

CLUSTERS OF STARS AND NEBULÆ.

On casting our eyes over the surface of the heavens on a clear dark evening, we at once perceive that in some directions the stars are clustered together, and in a few instances so compressed that the unassisted eye cannot discern the constituent members of the group, which assumes a hazy, undefined, or cloud-like appearance.

Amongst these close assemblages of stars may be mentioned the Pleiades in Taurus, Præsepe (popularly termed the Bee-hive) in Cancer, and a remarkable group in the sword-handle of Perseus, in which the stars are readily seen with a common night-glass, though the whole have a blurred aspect to the naked eye.

A telescopic survey of the heavens brings into view a great number of objects of a faintly luminous character, which are included under the general term *nebulæ.* A large proportion are either round or oval, brighter towards their centres than at their borders, and when viewed with small optical power very much resemble comets, for which they are often mistaken. In more powerful instruments, such as those brought into use by Sir William Herschel, a considerable number are clearly resolved into *clusters of stars,* like Præsepe, or the group in Perseus above mentioned: some hundreds or even thousands of stars are wedged together within the space of two or three minutes of arc, or less. Many others present a mottled glittering aspect when thus viewed, which shews that they are similarly constituted, but too distant for our telescopes to separate them into stars;

while, as might be expected, there are also very many that the most powerful optical means hitherto devised have altogether failed to exhibit otherwise than as faint cloud-like objects. They have the same form and general appearance as the resolvable nebulæ seen in common telescopes; and there is every reason for supposing them to be similar clusters of stars, but situated at far greater distances from the Earth.

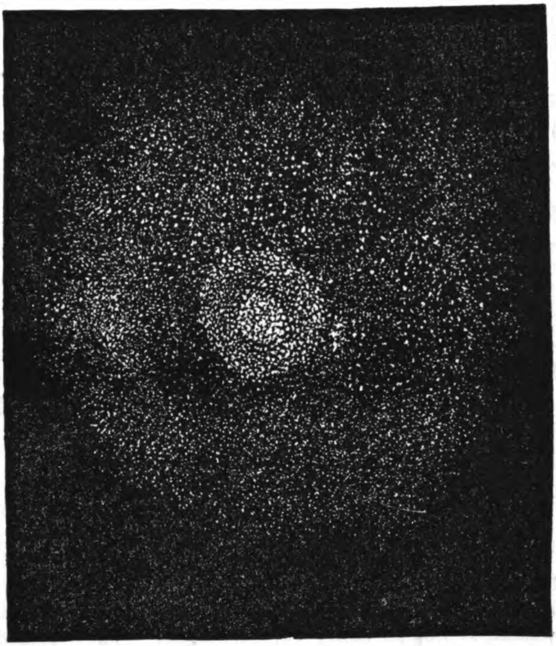

fig. 70. A Cluster of Stars.

One of the most magnificent *globular clusters* in the northern hemisphere occurs in the constellation Hercules, between the stars η and ζ. It is visible to the naked eye on dark nights as a hazy-looking object, and the stars composing it are readily seen with a telescope of moderate power. When examined in a powerful instrument, its aspect is grand beyond conception: the stars, which are coarsely scattered at the borders, come up to a perfect blaze in the centre.

Another splendid cluster is situate in the constellation Centaurus, and was discovered by Halley in 1677. To the naked eye it appears like a nebulous or hazy star of the fourth magnitude; while in the telescope it is found to cover a space two-thirds of the apparent diameter of the Moon, over which the stars are congregated in countless numbers.

Amongst the oval or elliptically-shaped nebulæ may be instanced a very conspicuous one in the constellation Andromeda, distinctly visible without a telescope as a cometary-looking object. Till very recently, this nebula defied all the optical power that could be brought to bear upon it to resolve it into stars, or even to afford any symptoms of its stellar character. Within the last few years decisive evidence of its consisting of stars has been obtained with the great telescope at Cambridge Observatory in the United States. It is commonly known as the *great nebula in Andromeda*, and was discovered nearly one thousand years ago, though not much noticed until attention was directed to its singular appearance by Simon Marius in 1612.

The globular and oval clusters are very far from constituting the entire nebulous contents of the heavens. On the contrary, nebulæ totally different in form and general features from the above present themselves in every direction; their number, however, is far inferior to that of the class we have described. The following are the most striking varieties:

1. Annular or ring-shaped nebulæ.
2. Planetary nebulæ.
3. Spiral nebulæ.
4. Nebulous stars.

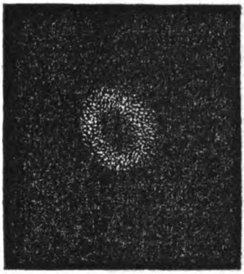

fig. 71. The Annular or Ring-Nebula in Lyra.

Of the first of these varieties, *annular* nebulæ, the heavens afford very few examples.

The most remarkable instance occurs in the constellation Lyra, between the stars β and γ. It is a well-defined object, nearly, though not perfectly, round, and may be seen with ordinary telescopes. The gigantic telescope of Lord Rosse shews it to consist entirely of minute stars. Though apparently a small nebula, its actual dimensions must be enormous: even supposing it no further from us than 61 Cygni, the diameter of the ring would be 20,000 millions of miles; and it is pretty certain that its real distance must be incomparably greater than that of the above star.

Planetary nebulæ are found in greater numbers than the annular ones; but their nature is not so easily comprehended. They exhibit discs of uniform brightness throughout, often very sharply defined at the borders, or only a little curdled or furred, as the edges of a planet frequently appear when the night is unfavourable for telescopic observation. They are called planetary nebulæ, from the great resemblance they offer to the discs of planets. Not far from the star β in Ursa Major is a fine nebula of this kind. It is nearly 3′ in diameter, very bright, and of equable light on its whole surface. One in the Southern Cross is described by Sir John Herschel as of a deep blue colour, its edges sharply defined, perfectly uniform in its light, which is about equal to that of a star of the seventh magnitude. Little or nothing is yet known with regard to the nature of these singular objects. They cannot be globular clusters of stars, otherwise they would be brighter in the middle than at the borders. It has been conjectured that they may be hollow spherical shells, or circular flat discs, situate nearly at right angles to our line of vision.

The discovery of *spiral* nebulæ is due to Lord Rosse, being one of the results obtained with the great reflecting telescopes constructed by that nobleman. The most interesting specimen of this class is a nebula known as No. 51 of Messier's catalogue, in the constellation Canes Venatici. It presents several luminous streams running in a spiral form from a centre, and surrounded by a narrow nebulous ring. Though not clearly resolved into stars with Lord Rosse's telescope, sufficient evidence is thereby afforded that it is so composed. Other nebulæ have similar spiral coils, but less distinctly marked than in the one above.

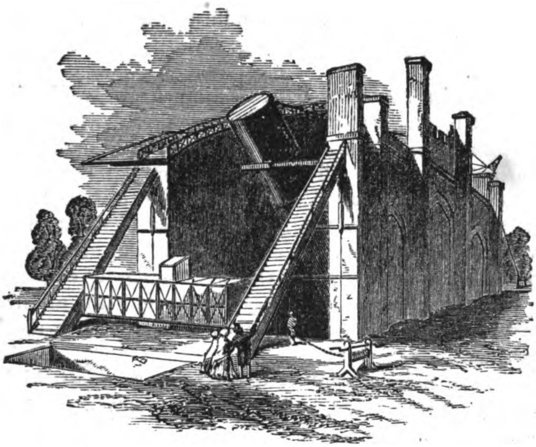

fig. 72. Lord Rosse's telescope, Parsonstown.

The nature of the *nebulous stars* is involved in as great obscurity as that of the planetary nebulæ. A faint nebulosity, usually of a circular figure and several minutes of arc in diameter, envelops a star which is placed in or very near the centre: in some cases it is sharply defined at the borders, in others it gradually fades away to darkness. The stars thus attended have nothing in their appearance to distinguish them from others entirely destitute of such appendages; nor does the nebulosity in which they are situated offer the slightest indications of resolvability into stars with any telescopes hitherto constructed. As instances of nebulous stars, may be mentioned one of the fifth magnitude, numbered 55 in Andromeda; another of the same brightness, numbered 8 in Canes Venatici; and one of the eighth magnitude on the borders of Perseus and Taurus, particularly pointed out by Sir William Herschel as a remarkable object of this class.

In addition to the nebulæ that properly belong to the foregoing divisions, there are others of forms more or less irregular, and occasionally of very considerable extent, which it is desirable to class by themselves. Of these by far the most remarkable is the *great nebula in the sword-handle of Orion,* discovered and figured by Huyghens about the middle of the seventeenth century. In its more prominent details there may be traced some slight resemblance to the wing of a bird. In the brightest portion are four conspicuous stars forming a *trapezium.* The nebulosity in the immediate vicinity of these stars is flocculent and of a greenish-white tinge; it was irresolvable until the completion of Lord Rosse's telescope, but in this instrument there are strong indications of its being composed of vast multitude of stars, far removed from us in the profundity of space.

There is an extensive and singularly shaped nebula between Sagittarius and Aquila, about five degrees north of the star μ in the former constellation. It resembles a horse-shoe, or capital Greek *omega* (Ω) in a telescope of moderate power. Sir John Herschel's drawing, in which the fainter portions brought out by his large reflectors are shewn, makes it very like two *omegas* joined together by a narrow ray at their adjacent extremities, and within one of the convolutions is situate a cluster of very minute stars. This object has pretty generally acquired the name of the *Horse-shoe nebula.*

The star η in the southern constellation Argo Navis, is surrounded by a collection of bright, irregular, nebulous masses, which Sir John Herschel traced over more than a square degree, and describes as offering a most wondrous spectacle. The powerful optical means employed by that astronomer during his residence at the Cape of Good Hope failed to give the smallest sign of resolvability. Upwards of a thousand stars are scattered over the nebulous region within the limits just specified, but are evidently quite unconnected with the nebula itself, which is doubtless situated at an immense distance beyond them. It occurs in a very crowded portion of the Milky Way, where each square degree contains two or three thousands of stars.

These extensive nebulæ of irregular figure are regarded by Sir John Herschel as outlying fragments, so to speak, of the Via Lactea, near which they are always found.

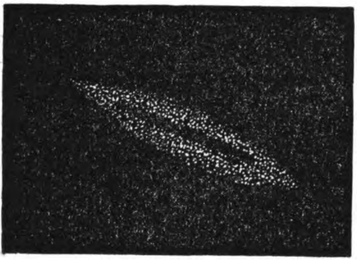

fig. 73. Oblique Ring-Nebula.

It would require a volume to treat of every variety of form and appearance by which the minor subdivisions of the nebulæ are characterised. Long narrow rays, double nebulæ both circular and oval, comet-like branches either with or without stars attached, elliptical nebulosities bisected by a narrow dark line, and nebulæ which resemble rings seen nearly edgewise, with many other varieties, occur in the catalogues of such objects formed by the two Herschels.

A nebula in the constellation Vulpecula greatly resembling in figure a *dumb-bell*, as viewed with common telescopes, is transformed by Lord Rosse's reflector into a double cluster of stars with a narrow connecting branch. Another in the vicinity of the star ζ in the southern horn of Taurus, which has an oval form in most instruments, is seen as a densely crowded cluster, with branches streaming off from the oval boundary like claws, so as to give it an appearance that in a measure justifies the name of the *crab-nebula,* by which it is often distinguished.

fig. 74. The Crab Nebula, as seen through Lord Rosse's Telescope.

THE NUBECULÆ OR MAGELLANIC CLOUDS.

In the southern hemisphere, not far from the pole of the equator, are two nebulous clouds of unequal extent, the greater covering an area about four times that of the lesser one. They were termed *Magellanic clouds,* after Magellan the early circumnavigator, a name still in very common use, but on astronomical maps they are usually called the *nubeculæ, major* and *minor.*

Both these cloud-like masses are distinctly visible to the naked eye when the moon is absent; the smaller one, however, disappears in strong moonlight. Their luminosity is white and diffused, resembling that of the Milky Way. Sir John Herschel examined these remarkable objects with his powerful instrument at the Cape of Good Hope, and describes them as consisting of swarms of stars, globular clusters, and nebulæ of various kinds, some portions being quite irresolvable, and presenting the same milky appearance in the telescope that the nubeculæ themselves do to the naked eye.

It is believed that the nubeculæ are independent of the Via Lactea, since they offer combinations of nebulous forms which rarely occur in that zone.

SYNOPTICAL TABLES OF THE PLANETARY SYSTEM.

THE SUN AND PRINCIPAL PLANETS.

Name of Planet.	Mean distance from the Sun. (The Earth's = 1.)	Sidereal period of revolution in days, hours, and minutes.	Inclination of orbit to the ecliptic in 1800.	Diameter in English miles.	Time of rotation on axis.
		d. h. m.	° ′ ″		h. m.
The Sun . . .	..	..	..	887,000	607 48
Mercury . . .	0·38710	87 23 16	7 0 9	2,950	24 5
Venus	0·72333	224 16 50	3 23 29	7,800	23 21
The Earth . .	1·00000	365 6 9	0 0 0	7,912	23 57
Mars	1·52369	686 23 31	1 51 6	4,500	24 37
Jupiter . . .	5·20279	4332 14 2	1 18 51	88,000	9 55
Saturn	9·53877	10759 5 16	2 29 36	73,000	10 16
Uranus . . .	19·18263	30686 17 21	0 46 28	36,000	Unknown
Neptune . . .	30·03683	60126 17 5	1 46 59	35,000	Unknown

THE MINOR PLANETS.

Name of Planet.	Period in days.	Name of Planet.	Period in days.	Name of Planet.	Period in days.	Name of Planet.	Period in days.
Flora . . .	1193	Hebe . . .	1380	Astræa . .	1511	Ceres . .	1682
Melpomene .	1269	Fortuna . .	1394	Irene . .	1515	Pallas . .	1686
Victoria . .	1303	Parthenope .	1399	Egeria . .	1516	Calliope .	1816
Vesta . . .	1326	Massilia . .	1400	Eunomia .	1567	Psyche . .	1848
Iris . . .	1346	Lutetia . .	1402	Thalia . .	1576	Hygeia . .	2043
Metis . . .	1347	Thetis . .	1430	Juno . .	1592		

THE MOON.

Mean distance from the Earth	238,000 miles.
Sidereal period of revolution	$27^{d}\ 7^{h}\ 43^{m}$
Diameter	2160 miles.
Inclination of the orbit	5° 8′ 48″

SATELLITES OF JUPITER.

Satellite.	Sidereal period of revolution round the primary.	Distance in semi-diameters of Jupiter.
	d. h. m.	
I.	1 18 28	6·049
II.	3 13 15	9·623
III.	7 3 43	15·350
IV.	16 16 32	26·998

SATELLITES OF SATURN.

Satellite.	Sidereal period of revolution round the primary.			Distance in semi-diameters of Saturn.
	d.	h.	m.	
I.	0	22	36	3·361
II.	1	8	53	4·313
III.	1	21	18	5·340
IV.	2	17	41	6·840
V.	4	12	25	9·553
VI.	15	22	41	22·145
VII.	21	4	20	25·02
VIII.	79	7	55	64·359

SATELLITES OF URANUS.

Satellite.	Sidereal period of revolution round the primary.			Distance in semi-diameters of Uranus.
	d.	h.	m.	
I.	2	12	17	6·94
II.	4	3	28	9·72
III.	8	16	56	15·89
IV.	13	11	7	21·27

SATELLITE OF NEPTUNE.

Sidereal period of revolution	$5^d\ 21^h\ 4^m$
Mean distance from Neptune	236,000 miles.

THE END.

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