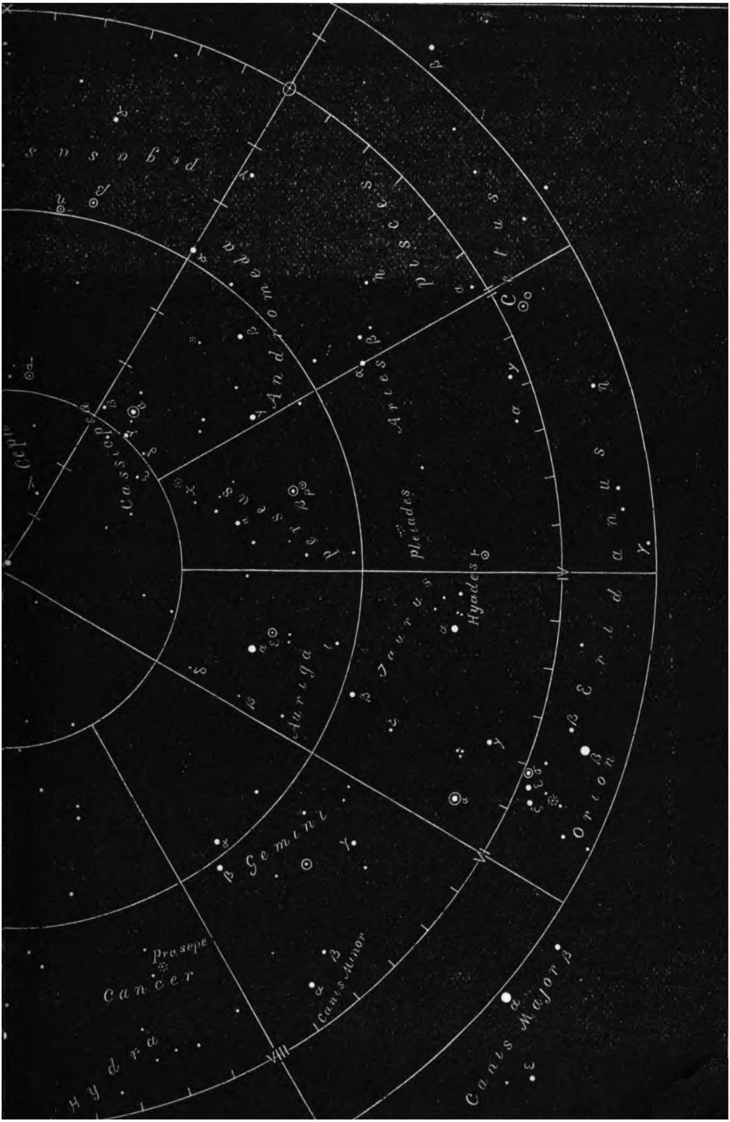
Capricornus
Sagittarius
Aquila
Delphinus
Cygnus
Lyra
Ophiuchus
Hercules
Scorpio
Serpens
Libra
Corona
Bootes
Draco
Ursa Minor
Ursa Major
Canes Venatici
Coma
Virgo
Leo
XX
XVIII
XVI
XIV
XII
Var.
Neb. or Cluster


Cepheus
Cassiopea
Pegasus
Andromeda
Pisces
Cetus
Perseus
Aries
Auriga
Taurus
Pleiades
Hyades
Eridanus
Orion
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MANUALS OF ELEMENTARY SCIENCE.

ASTRONOMY.

BY

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PREFACE.

ALTHOUGH this little Manual is quite elementary in its character, my aim has been to make it precise rather than popular in its language, and I have therefore entered on certain points which will probably present some difficulty to the beginner. I trust, however, that a reader of intelligence will be able, with a little attention, to follow the explanations given, brief though they are. In order to avoid circumlocution, I have found it necessary to introduce a few technical terms, which are explained in the text, and of which the reader will do well to grasp the meaning thoroughly, as any confusion on such points will add greatly to his difficulties afterwards.

In every case I have taken the numerical data given in this little book from the latest original sources, putting them into the form which appeared to me to give the clearest idea of the relations of the Solar and Sidereal Systems. With this object I have avoided, as far as possible, the use of large numbers, which simply bewilder the imagination; and have endeavoured to express the proportions of the quantities involved, choosing the unit best adapted to the immediate object in view, and omitting all unnecessary figures. It is only by gradual steps that man can rise to the conception of the distances of the stars.

Some of the questions discussed are still to a certain extent open, but they are among the most interesting in Astronomy; and my aim has been not only to give facts but also to suggest further enquiry on the part of the reader—and though some few results are not altogether free from doubt, I trust that he may have but little to unlearn when he enters more deeply into the subject.

W. H. M. CHRISTIE.

BLACKHEATH, *May*, 1875.

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ELEMENTARY ASTRONOMY.

CHAPTER I.

THE most casual observation suffices to show us that the Sun rises in the east, gets gradually higher till it reaches its greatest elevation in the south,* when it begins to sink, finally setting in the west only to rise again in the east and perform the same round next day.

If we turn to the stars at night we shall find something similar, but on examining more closely it will be seen that some of them are longer above the horizon than others, and that certain stars never set but remain constantly in view. If we watch these latter we shall find that there is one star which hardly changes its position, keeping constantly at nearly the same height, whilst the other stars appear to circulate round it at different distances. This star is called the Pole-star, for a reason which will presently be apparent. Now amidst all this diversity of movement there is one feature which is common to all, it is that every star returns to the same position after the lapse of twenty-four hours, and in this interval it will have described a circle. This latter fact may be rudely verified as follows:—Joint two rods together like a pair of compasses and rest one of them in forks so placed that it points to the Pole-star, then if the other rod be pointed to any other star it may be made to follow the star in its course by simply turning the first rod round in its forks, without altering the opening of the joint.

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* The reader is supposed to be in Europe, or other northern countries. For southern countries it will be sufficient to substitute south for north.

The motion will be thus like that of a pair of compasses, one leg of which is kept in an upright position as it turns. The second leg will, under these circumstances, describe a circle, as may be seen by running the upright leg through a sheet of cardboard (or stiff paper) held horizontally at such a height that the other leg, as it sweeps round, just touches it.

If we look a little more closely we shall find that the fixed rod will not continue to point exactly to the Pole-star all through its course, and that if we direct the rod in the forks to a point which is mid-way between the highest and lowest and the most easterly and westerly positions of the Pole-star, we shall get a point about which this star (as well as all others) describes a circle, the other leg of our compasses following it exactly in its motion by simply turning about the fixed leg.* This point is called the Pole of the heavens, and the daily motion of the stars may be represented almost exactly by supposing them (as the Ancients did) to be fixed in a hollow globe which spins once in twenty-four hours round an axis passing through the pole, so that the stars would in that time describe circles of different sizes, but all having their centres at the pole. But though this represents the movements of the stars, such a crystal sphere can have no real existence, for we shall presently see that the Sun is more than ninety millions of miles off, and the nearest of the stars are hundreds of thousands of times that tremendous distance from us, and a material sphere of that size spinning round once a day is of course quite out of the question. We are thus led to conclude that the diurnal motions of the stars cannot be real, but are only apparent, arising from our own movement in an opposite direction, just as when we spin rapidly round in one direction,

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* A telescope mounted on one of the legs of our compasses so as to follow any star in its daily motion by simply turning about the other leg (which is then called the Polar Axis) is termed an Equatorial. The turning of the axis may be effected by means of clock-work, and the telescope will then continue to point to the star for a length of time, during which it can be steadily gazed at.

the chairs, tables, and other objects in the room all appear to turn round at the same rate but the opposite way, the part of the ceiling directly overhead being the only point which appears stationary, just like the pole of the heavens. And this gives us some clue as to what our real movement and that of the earth, on which we stand, must be. The earth must be spinning round an imaginary axis, pointing nearly in the direction of the Pole-star, and carrying us and all terrestrial objects round with it once in twenty-four hours. But if we accept this explanation, how will the shape of the earth accord with such a motion? The portion of the earth which we can see at any one time appears a flat (or undulating) plain, bounded by a line—the horizon—where the sky seems to meet it; but we must not hastily conclude from this that the whole earth is a flat plain, for what we see is only a perspective view of a very small portion. If we look out over an expanse of sea (which is free from the irregularities of the land) it will be easy to assure ourselves that it is not really a plane,* for ships appear to sink lower and lower as they move away from us, so that first the hull and then the lower sails are cut off by the sea between us and the ship, whilst on ascending a cliff the lower sails and hull again come into sight. This shows that the surface of the sea is really curved (convex), for we know that objects disappear behind an undulation of the ground in exactly the same way, and that by ascending a hill they come into view again as soon as the visual line from the object to our eye clears the top of the swell in the ground.

There is another circumstance which now helps us materially in finding the shape of the earth. Wherever we are, whether on the top of a mountain or on board a ship at sea, the portion of the earth which we can

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* A plane is a flat *surface*, like an extremely thin sheet of paper, or the surface of a table, but of unlimited extent. Thus the plane of a circle is the flat surface in which the circle lies, boundless in every direction.

see, always appears a circle; though when we are at a considerable height, this circle seems much smaller, whilst we really see a larger portion of the earth's surface. Now the only figure with which we are acquainted which appears circular from all points of view and at all distances is a globe, and further, we know that this seems to grow smaller as we remove the eye from near its surface, whilst the actual portion of it which we see is really larger. This may readily be verified by means of a terrestrial globe or a large ball, but it must be remembered that in the actual case the distance from the earth's surface to which we can get would be represented on an 18-inch globe by about the thickness of a sheet of paper. From all this we infer that the earth is a globe, which rotates about an axis nearly in the direction of the Pole-star, and this conclusion is supported by what is observed of the motions of the stars in other countries. Any one who makes a voyage to southern latitudes will observe that the pole about which the stars revolve, while keeping the same position near the Pole-star, appears to sink as he journeys south, in consequence of which those stars, which are only just visible in these climes in the southern horizon, get higher and higher, and new constellations come into sight. This goes on till the Pole-star sinks in the northern horizon, when it is seen that there are really two poles about which the heavens appear to turn, one on the northern and one on the southern horizon; from which it is clear that the direction of the axis of motion is in the horizontal plane. The point of the earth at which this is the case is said to be in the equator, because it is equidistant from the two poles of the earth. The celestial equator is a great circle,* of which the plane is parallel to the earth's equator, and which, therefore, lies half-way

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* A great circle of a sphere (or globe) is one of which the plane passes through the centre of the sphere, dividing it into two equal parts or hemispheres. A small circle divides the sphere into two unequal parts.

between the poles of the heavens. It is advisable here to distinguish clearly between the pole of the heavens and the pole of the earth. The former is simply the *direction* of the line about which the stars appear to turn, or about which the earth really turns, whilst the latter is the extremity of the axis through the earth's centre about which it turns, and it has, therefore, a definite position on the earth as well as a definite direction in space. As there are two ends to a straight line, there are of course two poles, which are distinguished as north and south. To return to our traveller. After crossing the equator he will find that the southern pole (though it is not distinguished by any bright star near it like the Pole-star) rises higher and higher till it reaches the same height above the southern horizon as the north pole had originally above the northern, when the traveller has traversed the same distance south of the equator as he had previously done before reaching it; and he will further have remarked that the north pole sinks, or the south pole rises, through an angle of one degree* for every seventy miles he travels south.

All this is exactly what we should expect if the earth be a globe spinning about an axis, for in this case this axis, being in the direction of the pole of the heavens, would remain fixed among the stars, whilst the horizon (which is the direction of the surface where the spectator is) would change as the observer moved, so that instead of the Pole-star approaching the horizon, it is really the horizon which approaches the direction of the Pole-star. At the equator the Pole-star will be in the horizon, and will rise one degree for every 70 miles we travel north (owing to the tilting of the horizon), until at the pole, after having travelled over 6,200 miles, it would be 90° high, or in the zenith.† Hence

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* A right angle, which is the angle of a square or that formed by two perpendicular lines, is divided into ninety equal parts, called degrees, ninety degrees being usually written thus—90°.

† The point directly overhead.

the circumference of the earth, which is four times the distance from the equator to either pole, is 25,000 miles about, and the diameter 7,900 miles, the circumference of a circle being about $3\frac{1}{7}$ times its diameter (more exactly 3·1416). Strictly speaking the earth is not a perfect globe, but more like an orange, bulging out slightly at the equator, a result of its spinning round so rapidly, which tends to throw the particles at the equator off, like water from a mop. The amount of this bulging is however very small, being only $13\frac{1}{4}$ miles. As a point on the earth's equator moves round in a circle of the above size in one day, it must be moving at the rate of over 1,000 miles an hour, or 1,500 feet a second, which is more than the speed of a cannon ball. This motion is so smooth, however, that we feel nothing of it, as all the objects round us on the earth (including the atmosphere) move together with ourselves. But if it were not for the attraction of the vast mass of the earth, which pulls all bodies towards its centre (making a stone thrown up in the air fall back to the surface), we should fly off just as a stone whirled round in a sling does when the pull of the string is let go. It may seem very difficult to believe that we can really be moving at such an enormous speed, but unless we admit this motion we must suppose the stars to be swung round us with a velocity many million times greater; and, besides this, there is direct proof that the earth is moving in the way we have explained. This is given by the gyroscope, which is nothing but a top with a heavy disc, suspended in gymbals, so that it is free to turn in any direction. When this is set spinning rapidly, it requires great force to twist it out of its direction, as any one may readily experience with the ordinary toy gyroscopes. If left to itself, then, we know that its axis will continue to point in the same direction, and as it appears to follow a star, to which it is once pointed, in its daily course from rising to setting, we may conclude that the star is really fixed, and the motion which it appears to have in common with the gyroscope is really caused by the spinning of the earth about its axis once in every twenty-four hours.

From what precedes, we see that the elevation of the pole measures the distance of the observer from the equator, and this is called the latitude of the place, north or south, as the north or south pole of the heavens is elevated. This latitude is measured in degrees, the distance from either pole to the equator being ninety degrees, or, in other words, the latitude of the pole is 90°. The equator, being the line formed by all points which are equidistant from the two poles, will be a circle, and, further, all places which have the same latitude, being at the same distance from the pole, will lie on a circle parallel to the equator; this is called a circle of latitude. Thus when we say that a place has a certain latitude, we fix its position so far as to settle that it lies somewhere on a certain circle, which is determined by measuring the elevation of the pole. This is readily done; for the pole lies midway between the highest and lowest positions of the Pole-star, being at the centre of the circle which this star describes, and it is only necessary to measure the angular elevations above the horizon of this star at its highest and lowest points by means of a divided circle. The same method would answer equally well if applied to any other star tolerably near the pole. But to fix the position of any place on the globe it is necessary to know whereabouts on the circle of latitude it lies, and this is practically a more difficult matter, and one that requires for its determination, astronomically, the introduction of a new element—time. For the measurement of time uniform motion is required, and this condition is secured more or less perfectly in the motion of the hands of a clock under the control of a pendulum, or of a watch or chronometer regulated by the balance and its spring; but the rotation of the earth supplies us with the only perfect timekeeper with which we are acquainted, and the apparent movement of the stars resulting from it, really serves to regulate all our clocks and watches. In fact the heavens may, for this purpose, be compared to one of those lamp clocks in which the globe turns round and brings the hours painted on it up to an index. The stars represent the hours and minutes, though not placed at regular intervals: but where are we to find the index which is to tell us the time? We must look for this in the movements of the stars themselves. We saw that they describe circles about the pole, so that their paths are tilted with reference to the horizon; the highest point of the star's course will evidently be a convenient point at which to fix our index, and a little consideration will show that the highest point of each circle will be where it meets a vertical plane through the north and south points (or, in other words, through the zenith and pole), for the leg of the compasses, of which we have spoken before, and which we suppose to follow the course of any star, will evidently reach its highest point when the plane formed by the two legs (one of which points to the pole) is vertical. This plane then, which is called the meridian, may be taken as our index. Though this is only an imaginary index it can be used as readily as if it really existed in the heavens, by simply mounting a telescope on trunnions, like a gun, and making it swing vertically, north and south, so as, at the proper elevation, to point exactly to the pole.* When such a telescope points exactly to any star, we know that the star has come up to the index, and when it next comes up to this position we know that exactly twenty-four hours have elapsed, and if our clock does not indicate the same time as before, we know at once that it has gained or lost so much in the day. It is thus easy to find how our clock is going; but to tell the time at any instant it is necessary to

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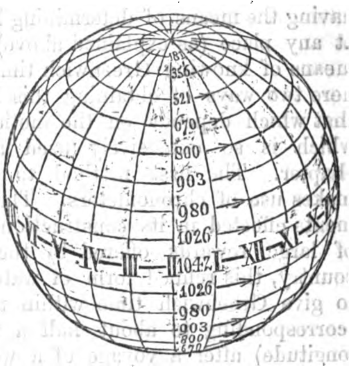
* A telescope so mounted is called a transit instrument. For greater accuracy it is provided with cross wires (or spider webs) fixed at the place where the image is formed, so as to mark the centre of the field. These cross wires being seen at the same time as the star, enable us to judge when the telescope is pointed exactly to it.

know the intervals at which the stars are placed on our celestial clock, and this can best be done by noting with our clock the difference of times between the arrival of pairs of stars at the index (their meridian passage or transit as it is called) and correcting this for the proportional gain or loss of the clock in the interval, on the assumption that it has gone uniformly for twenty-four hours; by repeating such observations a great many times and taking the average, the irregularities of the clock will, on the whole, nearly balance, and an accurate measure of the interval of transit of each pair of stars be arrived at. Thus taking any particular star as our starting point for 0^h, we can easily find the time at any other part of the twenty-four hours. But it is more convenient for purposes of ordinary life to take the sun as our starting point, though on account of his irregular apparent motion among the stars (which will be discussed more fully in the next chapter), he does not make quite such a good clock as the stars, gaining at certain parts of the year and losing at others, so that we must make allowance for his being so many minutes fast or slow, just as with an ordinary clock. The time at which the sun comes up to our index is called apparent noon, and if we make allowance for his being fast or slow, we readily get the instant of mean noon (as it is called) at which our clocks ought to point exactly to 0^h.

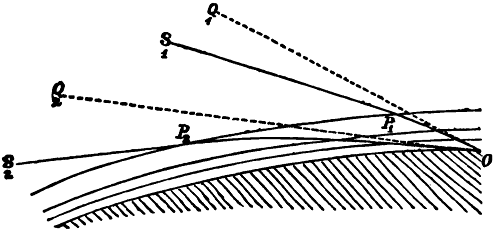
We may now proceed with the question of longitude. For convenience of illustration we compared the heavens to a globe which turned round and brought the hours up to a fixed index, but really it is the celestial globe which is fixed and the index or meridian which moves. Now let us take two places with two different indexes, or meridians, which, by the rotation of the earth, are brought up successively to the Sun, giving the instants of noon for the two places respectively. When it is noon for the second place the Sun will be west of the meridian at the first, and the time that has elapsed since the Sun was in the meridian of the first place, will be the same part of the time between successive returns of the Sun to this meridian, as the angle turned through by the earth to bring the second meridian up to the Sun (from the position for noon at the first station), is of the angle turned through from one noon to the next. 'The same would hold for the stars, moon, or planets, and the difference of longitude of the two places will be the same part of 24^h, if expressed in time, or of 360° if expressed in angular measure. The longitude of a place, then, is nothing but the difference between its time and that of the place selected as our starting point (Greenwich for Englishmen), so that having the means of determining local time (*e.g.*, noon) at any place (as explained above) what is wanted is a means of knowing Greenwich time. We may mention here two ways of obtaining this knowledge, reserving that which depends on the motion of the moon, and which is so extensively used at sea, for a future chapter. The first method to which we shall refer makes use of chronometers. Thanks to the improvements effected in its construction, under the stimulus of large rewards offered by the Government of this country, this refined form of watch may be relied on to give Greenwich time within two or three seconds (corresponding to about half a mile in the deduced longitude) after a voyage of a week or ten days, so that the longitude may be found to that degree of accuracy after a short voyage. But there is another method of far greater accuracy which has been introduced of late years wherever the telegraph extends to. In this method Greenwich time is obtained by a signal sent from the Royal Observatory at a known instant of Greenwich time; such signals are sent out every morning at 10^h a.m., at noon, and at 1^h p.m. exactly, and are distributed all over the United Kingdom by the Post-office telegraphs, their chief use being to regulate time on railways and in public buildings.

From what precedes it is clear that the position of any place on the earth is completely determined when we know the circle of latitude on which it lies, and also its position on that circle, *i.e.*, its latitude and longitude; but the reader has, perhaps, not got a very clear idea of what is represented by longitude on the earth itself. To assist him in this, we should explain what is meant by a meridian on the earth, having already explained what is the astronomical meridian of a place. If we start from any place and travel due north or due south we shall always remain in the same vertical plane through the pole, which will therefore continue to be our meridian; so that all the places we pass through will have their noon at the same instant, and therefore have the same longitude. The line along which we travel is called a terrestrial meridian, and, since we are evidently going directly towards the pole, all meridians pass through the poles. We may, therefore, conceive the earth as divided into a series of circles of latitude, all parallel to the equator, and into a series of circles of longitude or meridians, all passing through the poles, which, by their crossing, define the positions of places on the earth. These are the lines which are drawn on maps, though for the sake of clearness only those at convenient intervals are put in; it is, however, necessary to imagine a circle of latitude and one of longitude passing at right angles to each other through every point of the map. The figure represents the circles of latitude drawn for every 10°, and the meridians for every hour, the numbers placed between the meridians of I^h and II^h represent the number of miles traversed



by places on the corresponding circles of latitude in one hour.

We have not yet spoken of a very important part of the earth, and that which, in fact, renders our globe habitable—its atmosphere. At every point of the surface we find air, which makes its presence felt in various ways, and which exerts a pressure of 15lbs. on every square inch of surface of a vessel from which the air has been exhausted. This pressure can be measured accurately by the mercurial barometer, an instrument in which the pressure of the air on the mouth of a vertical tube, closed at the upper end and exhausted of air, is balanced by the weight of mercury which it will hold suspended. It is in this way found that the pressure at the sea level is the same at all parts of the earth, being equal to the weight of a column of mercury about 30 inches high, and having the same section as the surface on which the pressure is exerted, which corresponds to a column of air of the same density throughout as that at the surface, and 27,000 feet, or about five miles high. But on rising above the sea level, whether in ascending a mountain or in a balloon, we soon find that the pressure decreases less rapidly than would be the case if the atmosphere remained of the same density as at the surface: thus we have to ascend to 2,850 feet to get through the first tenth of the atmosphere; through 3,200 feet more to get through the next tenth; through 3,650 feet more for the third tenth, and 4,250 feet more for the fourth tenth, and so on. In this way it would require an ascent of about 18,000 feet to pass through the lower half of the atmosphere (as measured by its weight) and an ascent of about 30,000 feet to traverse the lower two-thirds, starting in each case from the sea level. Since the pressure of the atmosphere is due to the weight of the superincumbent air, it is easy to see that the air gets lighter, and therefore less dense, as we ascend, and this is in perfect accordance with the law that elastic gases expand, and so become rarefied, as the pressure is diminished. Thus we see that the earth is surrounded by a shell of air in contact with it, and decreasing in density as we proceed outwards, so that at a height of less than 10 miles it is too rare to be capable of supporting human life. Small though the extent of our atmosphere is, as compared with the size of the earth, it modifies in a wonderful degree the climate of our globe, and further gives rise to two important astronomical phenomena—refraction and twilight. When a ray of light passes from one medium into another which is more dense, it is bent away from the surface of the dense medium. This is precisely what happens when a ray from a heavenly body enters our atmosphere from outer space; and as the layers get more and more dense, it gets more and more bent away from the surfaces of the layers (which are parallel to the horizon) in its passage through the atmosphere to the earth's surface. Thus the rays from a star which entered the atmosphere in a certain direction SP will, when they reach us, have a direction QO further away from the horizon, and as the star is seen in the direction, which the rays from it have when they fall on our eyes, it will appear higher than its true position, owing to the effect of the atmosphere. This effect is called refraction, and its amount is greater



REFRACTION.

The rays from two stars coming to the observer at O, along S_1P_1O, S_2P_2O, are bent downwards in passing through the atmosphere, and reach the observer in the directions of the dotted lines Q_1O, Q_2O, along which the two stars are seen.

the nearer the body is to the horizon. The consequence of this is that the northern stars do not appear to describe exact circles about the pole, the lower half of their course being very slightly flattened, as they are raised more by refraction in the part near the horizon than when they are higher in the upper half of their paths. This effect is, however, in most cases very slight, not being perceptible to the naked eye, and when allowance is made for it the diurnal arcs are found to be true circles. Another effect of refraction is that the day is lengthened at the expense of the night; for when the sun is really on the horizon, he is apparently raised above it by more than his own diameter, and has, therefore, this space further to travel before he sets, causing a delay of about 2^m. Similarly his rising is hastened, so that the day is lengthened by some 4^m. But twilight has a far more important effect for practical purposes on the duration of daylight, for after the Sun has set he still continues to illumine the clouds and upper regions of the atmosphere, and this light is reflected irregularly in all directions, some of it reaching that part of the earth which would otherwise be in absolute darkness after the Sun had set. It is found by observation that twilight ceases to be perceptible when the Sun is more than 18° below the horizon, and it results from this, that at a height of 50 miles, or about an eightieth part of the earth's radius, the atmosphere is too rare to sustain particles capable of scattering the sun's light. As the duration of twilight is simply the time taken by the Sun to descend 18° below the horizon, it follows that twilight is much shorter in tropical countries, where the Sun descends perpendicularly to the horizon, than in polar regions, where his course is oblique, the pole being considerably elevated and the equator much inclined to the horizon. The diffused light of day may be referred to the same cause as twilight—the scattering of the Sun's light by particles of vapour in the air, more especially in the form of clouds.

CHAPTER II.

In the last chapter the apparent diurnal movement of the heavens (in which all the heavenly bodies partake) about the pole was dealt with; it is now time to treat of the apparent motions of some of these bodies among the stars, which, though much smaller in amount than the diurnal movement, yet affect it appreciably in certain cases. We will begin with the Sun, as its movements are the most important, and at the same time the simplest. We have seen that all the heavenly bodies have a diurnal motion about the pole in the direction in which a right-handed screw would be turned to screw it in at the north pole, or in the direction of the hands of a watch, which faces the north pole; and the Sun, Moon, and planets have the same general motion, though very slightly altered in amount by their apparent motions among the stars. If an observer notes at midnight the position of any bright star (south of the zenith), he will find at midnight a fortnight after, that it has got considerably to the west of its former position, and that it really was in that place an hour earlier, or at eleven o'clock. It is therefore evident that the stars have gained an hour on the clock, or, what comes to the same thing, that the clock has lost an hour on the stars. But the clock is regulated by the Sun, so that the Sun has been lagging behind the stars, or moving eastward among them at the rate of 4^m a day, or of an hour nearly in a fortnight. Our observer would find, on continuing his observations, that another hour was lost by the clock or gained by the star in the next fortnight, and so on, till the star finally disappeared in the evening twilight. He could then take another star, and in this way would find, as the general result of his observations, that his clock continued to lose uniformly at the rate of 4^m a day, and that at the end of one year it had lost 24 hours, having made the complete tour of the stars, so that the original star was again in its original position at midnight. The Sun would thus have gone completely round among the stars in one year, but it would have differed from the clock in this, that its lagging behind the stars would not have been uniform from day to day, being, at certain seasons of the year, rather more than 4^m a day, and at others rather less. For though our ordinary clocks are regulated primarily by the Sun, they do not indicate Apparent Solar Time, as shown by a sun-dial, but what is called Mean Solar Time, which is obtained by making a correction for the irregularity of the Sun's motion. It is this irregularity which we wish now to determime, and for this purpose we must refer to the stars, which are, as already explained, our only reliable time-measurers.

But before considering more fully the Sun's motion, we must find out more precisely the exact path among the stars which he describes. Every one has remarked that the Sun attains a greater height and is longer above the horizon in summer than in winter; and from what has been said in the last chapter it will readily be understood that for this to be the case the diurnal arc which he describes must be nearer the north pole in summer than it is in winter; in fact he is in summer north of the equator, and in winter south of it; but to learn more of his path recourse must be had to actual measurement of his distance from the equator at different times of the year. This can best be done by measuring at noon his angular distance from the zenith, and taking the difference between this and the distance of the equator from the zenith, which is equal to the latitude of the place (the celestial equator being vertical for any place on the earth's equator, and tilting one degree towards the south, as the north pole rises, for every degree of north latitude). Now the zenith distance of any heavenly body when on the meridian may be readily measured by attaching a vertical graduated circle, or arc of a circle, to the transit instrument described in the last chapter, so as to turn with the telescope. Such a circle will, if we have a mark on it to which an index points when the telescope is directed to the zenith, show by the position of the index on the circle the angle through which the telescope has turned from the zenith when it points on any object, such as the Sun, in other words, it will show the meridian zenith distance of the Sun. But we must first fix our mark, and this is best done, not by pointing the telescope vertically up, but indirectly. We know that the reflection of a very distant object in a lake appears depressed just as much below the horizon as the object is elevated above it, whatever be our height above the surface, a result which follows from the fact that the surface of water or any other fluid is horizontal. If, then, we point our telescope to the reflection of a star in a basin of water, or, still better, in a basin of mercury, we shall have to depress the telescope through an angle equal to that through which we have to raise it to point at the star directly, and if the position of the index on our graduated circle be noted in each case, the point half-way between the two will evidently correspond to the horizontal position. The mark for the zenith will have to be made at a point 90° from this, the zenith being 90° distant from any point of the horizon. Measures of the Sun's meridian zenith-distance being made in this way, and his distance north or south of the equator deduced from our knowledge of the latitude of the place, that is, the elevation of the pole, it is found that there are two days of the year exactly six months apart, viz., March 21 and September 21, when he crosses the equator. These points of crossing are called the equinoxes, because the day and night are then exactly equal all over the world, the part of the equator above the horizon being in all latitudes equal to the part below, so that a star or other heavenly body which is in the equator is 12 hours above the horizon and 12 hours below wherever the observer may be situated. At the vernal equinox, corresponding to March 21, the sun passes from south to north of the equator, and gets further and further north, but at a slackening rate, till June 21, the summer solstice, when he is about 23½° north of the equator. This is his turning point, and he then begins to approach the equator again, his distance from it decreasing at first very slowly, and then more rapidly, till he again crosses it at the autumnal equinox, but this time from north to south. His southward motion continues till December 21, the winter solstice, when he begins to move northward, arriving at the vernal equinox again on March 21. The time that elapses between the returns to the vernal equinox is not an exact number of days, being $365^d\ 5^h\ 48^m\ 50^s$ in solar time, or $366^d\ 5^h\ 48^m\ 50^s$ in sidereal time, there being one more sidereal day from the circumstance that the Sun has gone round once eastward, in the direction in which the earth spins, lagging continually behind the stars in its rising and setting. In order that the seasons may always fall at the same times of the civil year it is necessary to take account of the fraction of a day (nearly a quarter) over the 365; in the Gregorian calendar, which is that adopted generally, this is effected by making every fourth year (leap year) consist of 366 days, the extra day being added to February; but as the true year is really rather less than 365¼ days, the extra day is not added to any year which is an exact hundred, and would, therefore, naturally be a leap year (*e.g.*, 1700, 1800), unless the number of the century is also divisible by 4 (*e.g.*, 1600, 2000), and in this way three days are got rid of in every 400 years, making the discordance between the civil year and the truth less than one day in 3,000 years.

It will readily be understood that as the Sun takes six months to move from 23½° south to 23½° north, the change of declination or distance from the equator in one day is very small, in fact it is never more than ⅖° (less than the Sun's diameter), so that the diurnal course remains very nearly a circle described about the pole just as in the case of a star.

Before proceeding further it is desirable to explain how the position of a heavenly body is fixed. For a place on the earth we saw that its latitude, or the angular distance of the point from the equator, and its longitude, *i.e.*, the time required for the earth's rotation to bring the meridian of the place to the position originally occupied by the first meridian, or that through Greenwich, are sufficient to fix the position of the place; now the same system may be adopted for the stars, but in their case the angular distance from the celestial equator is called Declination, and corresponding to longitude, reckoned from an arbitrary first meridian we have Right Ascension, measured from the vernal equinox, in exactly the same way, *i.e.*, by the time which elapses before the meridian through the star occupies the original position of the meridian through the vernal equinox. We have here used the term meridian in the same sense in which it is used for the earth, but to avoid confusion with the fixed meridian, the great circle drawn from the pole through any star is called the hour circle of that star. Thus we have imaginary circles of declination and hour circles through every point of the sphere on which the stars appear to be projected, just as we have through every point of the earth circles of latitude and meridians.* Declination and Right Ascension, then, are to be considered as corresponding on the celestial globe to Latitude and Longitude on the earth; unfortunately the terms Latitude and Longitude in the case of the heavenly bodies have been applied to a totally different system of measurement, a circumstance that has given rise to much confusion of ideas.

So far we have spoken of time as determined from the Sun and from stars, without pointing out the distinction between the clocks, which are used in the two cases. A solar clock is regulated to show 0^h at noon and 0^h again at the next noon, but if such a clock were used for stars it would be found to have lost nearly 4^m between the successive passages of the same star across the meridian, in consequence of which we use for the

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* The circles on the Key Map (Frontispiece) represent the circles of 60° and 30° North Declination, the Equator and that of 15° South. The lines from the centre represent the Hour Circles for every two hours.

stars a sidereal clock, which is so regulated that exactly 24 of its hours elapse between successive transits of the same star. Such a clock is set so as to indicate 0^h exactly when the vernal equinox is on the meridian, and as this point may be taken as fixed among the stars, and therefore takes 24 sidereal hours to return to the meridian, it is clear that sidereal time must be used for right ascension, which measures the distance from the vernal equinox. With regard to terrestrial longitudes, we must use a solar or sidereal clock, according as we take transits of the Sun or of a star across the meridians of the two places. What we really want in this case is the proportion that the interval of time between the transits of the same heavenly body over the two meridians bears to the interval between its successive transits over the same meridian, and this proportion is the same whether both intervals are expressed in solar or in sidereal hours, but it is convenient to take the second interval as 24^h (solar or sidereal, according as the Sun or a star is used), and this determines whether the first is to be in solar or sidereal hours. The same consideration applies to all cases where time is used to measure the angular distance of two points. A homely illustration may put this in a clear light. In some parts of England a pound of butter is made into a roll a yard long, and sold by length. Suppose, now, that in France a pound of butter is made into a roll a metre long, then we shall clearly get the same quantity of butter whether we buy a quarter of a yard in England or a quarter of a metre in France; but if we buy a quarter of a yard in France we get less, and if a quarter of a metre in England more than our quarter of a pound. We have dwelt on this point because it is usually troublesome to beginners, from the want of a clear conception of the measure that is being used.

To return to the Sun. We have shown how to measure his declination. To find his right ascension we must first find the right ascensions of one or more stars by noting the difference of the times of transit (in sidereal hours) of the Sun when he crosses the equator at the vernal equinox, and of the selected stars, and then observe the interval (also in sidereal time) between the transit of one (or more) of the known stars and of the Sun. The Sun's right ascension will be found by adding this interval to the star's right ascension. If several stars be observed, the mean (or average) of the results from each star can be taken, and the final result will then be more accurate. This is a principle which is continually made use of in astronomy (and other observational sciences) to reduce the inevitable errors arising from the imperfections of our senses and of our instruments, all which affect a single observation, but very nearly balance one another when we take the mean of a large number of measures of the same quantity, the errors which make it seem too big being about as many as those which make it too small, on the principle that if a coin be tossed up a large number of times, it will turn up heads about as many times as it does tails. The Sun's position being thus found for every day of the year, we can plot down his course on an artificial globe, and we find in this way (or by calculation) that his apparent path is a great circle * inclined to the equator at at angle of 23½°, and cutting it at the equinoxes. The plane of this circle is called the ecliptic. The Sun's motion along this path is not quite uniform; about January 1 it is quickest, and about July 1 slowest, but the variation is only about $\frac{1}{15}$ of the whole, the daily motion ranging from 57′ to 61′. This variation, combined with the tilt of the Sun's path, which makes his motion more oblique to the equator at the equinoxes than at other times, causes an irregularity in the time as shown by the Sun, and if a clock be regulated to go uniformly with the Sun's average rate, the Sun will be

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* Any body which moves in a plane passing through the spectator, no matter what the path in that plane be, will *appear* to describe a great circle in the heavens, since a great circle is the curve in which the sphere is cut by a plane through the centre, *i.e.*, the spectator, and we refer the actual path to the sphere of the heavens, by looking along the plane in which it lies.

at certain times of the year fast or slow by the clock to the extent of 16 minutes, the amount by which the Sun is fast or slow being called the equation of time.*

Further, the change in the Sun's rate of motion is accompanied by a corresponding change in his apparent diameter, which is largest when the motion is quickest, the variation amounting to about a thirtieth part of the whole.† When an object increases in apparent size, either it must really be growing larger, or it must be approaching us. Now, in the case of the Sun, we have no reason to conclude that there is any real change of diameter, such an alteration of bulk being highly improbable, and we are therefore led to infer that he is nearer to us in January than in June by about one-thirtieth part.

If now we draw a circle to represent the ecliptic, and lay down on it the position of the Sun on every fifth day of the year, the lines drawn from the centre to these points will represent the directions in which the Sun is seen by us at the corresponding times; but as his distance changes, we must, to represent his apparent motion fully, set off on these radii lengths corresponding to his actual distance on these days. We thus conclude that the Sun *appears* to move round us once a year in a slightly oval and excentric path.

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* The Sun and clock are together four times in the year, viz.:—On April 15, June 15, Sept. 1, and Dec. 25; from April 15 to June 15, and from Sept. 1 to Dec. 25 the Sun is fast, the greatest error in the first period being nearly 4^{m} on May 15, and in the second period $16\frac{1}{3}^{m}$ about Nov. 3. From June 15 to Sept. 1, and from Dec. 25 to April 15 the Sun is slow, the greatest error in the first period being $6\frac{1}{4}^{m}$ on July 26, and in the second period $14\frac{1}{2}^{m}$ on Feb. 11. As the Sun is steadily losing on the clock from Nov. 3 to Feb. 11, his rising and setting will both be retarded from this cause, and thus the evenings will lengthen more than the mornings at the beginning of the year, though this effect is only apparent, being the result of our reckoning by clock time instead of Sun time.

† There is a curious optical illusion which makes the Sun and Moon seem much larger when close to the horizon; but this is only the result of having known objects, as trees and houses, to compare them with, which enables us to realise to a certain extent how immensely distant these heavenly bodies really are. The angular diameters (when carefully measured and corrected for refraction, which slightly *decreases* the diameter), agree exactly with the results of observations near the zenith.

But we have, so far, no more reason to suppose that the Sun is moving round the earth, than that the earth is moving round the Sun, for either supposition would explain the Sun's apparent motion, just as we saw that the apparent rotation of the heavens may be explained by a rotation of the earth in the opposite direction. Now there are several circumstances which lead us to conclude that it is the earth which goes round the Sun and not the Sun round the earth. In the first place, the Sun is enormously bigger than the earth, as we shall see when we come to discuss the means of finding his distance, which are quite independent of this question. Then, again, we shall find that there are other heavenly bodies of which the apparent movements can only satisfactorily be explained by supposing them to revolve about the Sun, at distances which, in the case of some of them, are many times that of the earth from the Sun, and as these bodies themselves are generally larger than the earth, the supposition that the Sun is carrying such masses along with him in his course round our diminutive earth is in the highest degree improbable. But it is when we come to discuss the physical cause of these motions that the absurdity of such an hypothesis is brought home to us.

In anticipation, then, of the conclusions of subsequent chapters, it may be taken that the earth revolves round the Sun once in a year in a slightly oval and excentric path in the plane of the ecliptic, at a distance of about 23,200 of the earth's semi-diameters, and with an average velocity of 18 miles a second (more than fifty times as fast as a cannon ball), moving over eight times her own diameter every hour. As the Sun's apparent diameter is 32′, or rather more than half a degree, at his mean distance, it follows that he is at a distance from us of 215 times his own semi-diameter, which is 108 times that of the earth.*

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* The arc corresponding to 1° at the centre of a circle being $\frac{1}{360}$ of the whole circumference, which is $3\frac{1}{7}$ times the diameter, it follows that the length of the arc of 1° is $\frac{1}{57}$ of the radius nearly.

Now although we may at first feel some difficulty in realising that our globe is moving at such an enormous speed without our being conscious of it, yet if we consider that the earth bears the same proportion to the Sun that a 12-inch globe bears to the dome of St. Paul's, we shall find it far more difficult to conceive that such an insignificant body as our earth is really the centre of the Sun's motion. But whether the earth be moving round the Sun, or the Sun round the earth, or both about some other point in the line joining them, their apparent motion will be the same; and as far as these two bodies only are concerned, we may consider the motion in that way which conduces most to clearness of explanation. So that just as we talk of the Sun, Moon, and stars rising and setting, though these are mere appearances, we may for the present speak of the Sun's annual motion round the earth; but when we have to consider the motion of another heavenly body relatively to the Sun, we must transfer our thoughts to him, and picture to ourselves what the appearances would be from that point of view. No error is involved in either way of speaking, provided we remember that we are only treating of relative motions. On this understanding we will proceed to show how the apparent (or relative) motion of the Sun gives rise to the seasons.

At the vernal equinox the days and nights, as before stated, are equal, and this is the case all over the world, the equator being everywhere divided into two equal parts by the horizon. From this point the Sun, moving along his oblique path, passes north of the equator, and two results follow from this, both of which cause places in the northern hemisphere to receive more heat from the Sun. In the first place the day is lengthened and the night shortened, so that the time during which heat is received from the Sun is increased; and in the second place the amount of heat received in every hour is greater on account of the greater elevation of the Sun, for his rays have a less thickness of the atmosphere to traverse and heat on their way, and further, a larger proportion of them strike a surface when they fall perpendicularly than when obliquely, just as in a driving shower a larger number of drops will fall on an umbrella when the stick is held in the direction of the shower than when it is held upright. With regard to the loss of light and heat in passing through the atmosphere, it is sufficient to remark the enormous decrease in brightness of the Sun near sunset to appreciate the influence of this cause, which reduces the Sun's brightness at 5° elevation to one-fifth of what it would be at the zenith. Now we must remember that the temperature of any body results from a series of exchanges with surrounding bodies, heat being received and at the same time sent out; hot bodies send out more heat than they receive, and the reverse is the case with cool bodies. Now the earth receives a balance of heat from the Sun; if it sends all this heat away into space all round it will remain in the same state as before, but if it receive more than it can send away it will get hotter, and this is the case with places in the northern hemisphere at the time we are considering; for, as we have seen, such places receive more heat from the Sun in the day, and have less time in the night to send it away and thus cool down, than was the case when the Sun was at the equinox. But the quantity of heat received by the whole earth and sent out into space remains the same, for in southern latitudes the Sun is below the equator (the north pole being below), and the days are shorter than the nights, so that those countries get cooler than they were at the vernal equinox. Now these opposite effects in opposite hemispheres go on increasing as the Sun gets further and further north, till June 21; the northern hemisphere has by that time stored up such an accumulation of heat in the soil itself, that it does not begin to grow cooler till some time after, just as a kettle taken off the fire will continue to boil on the hob, though the heat there is not sufficient to set it boiling. But this heat from the soil will be gradually dissipated as the Sun moves southwards in the autumn, and the weather will grow colder and colder in northern latitudes, the reverse taking place in the southern hemisphere. Such an accumulation of ice and snow will be formed in the northern hemisphere, in consequence of the abstraction of heat which then takes place, that the arrears will have to be cleared off after the winter solstice, before the northerly motion of the Sun produces any effect.

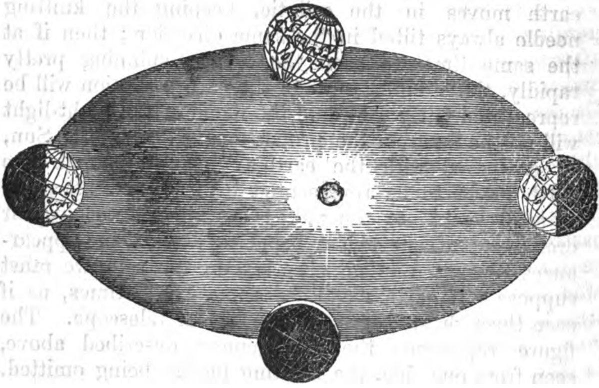
Thus we may consider winter in the northern hemisphere (or summer in the southern) to correspond to the months of December, January, and February; spring (or autumn) to March, April, and May; summer (or winter) to June, July, August; and autumn (or spring) to September, October, and November. But there are certain portions of the earth where this division does not hold, viz., the regions near the equator. As the Sun crosses the equator twice, he is vertical at such places twice in the year, and the same will be true for any place which is less than 23½° north or south of the equator, since for such places the celestial equator is less than 23½° from the zenith. The belt of the earth included between these circles of latitude is called the tropics, and, since the heat at any place is greatest when the Sun is vertical, these places have two summers; but really the change is very slight, and the year is usually divided into the wet and the dry season, the term winter, as understood in our latitudes, being hardly applicable. We may here allude to two other regions of the earth in which this word implies much more than it does with us, conveying the idea of darkness as well as of cold, of absence of light as well as of heat. The Sun at midwinter being 23½° below the equator, will not rise above the horizon of any place at which the celestial equator does not reach an elevation of 23½°, which will be the case when the place is less than 23½° from either pole, or has a latitude (north or south) greater than 66½°. The circles of latitude 66½° north and south are called the Arctic and

Antarctic circles respectively, and the belts included between them and the tropics are called the north and south temperate zones. In the Arctic and Antarctic regions it is clear that the Sun will in winter remain below the horizon during the whole time that he is further below the equator than the distance of the place (in degrees) from the pole of the earth, and that he will in summer remain above the horizon for a similar period, so that the alternation of day and night is so far modified, that in summer we have sunlight continuously for weeks or even months at a time, and in winter we have a night of the same duration. At the poles themselves these periods last for six months each, so that there is only one day and one night in the year, but of course the Sun continues to circle round the pole once in every twenty-four hours just as in other latitudes, though, like the stars of the Great Bear with us, he never dips below the horizon. In this, as in many other cases, the ambiguity of the term day causes some confusion.

We have already spoken of the effect of twilight in lengthening daylight; its influence is felt in a remarkable degree in Polar regions, some light being received from the Sun in midwinter even at places as near as 5° to the pole.

Though, as has been already stated, it is perfectly legitimate to explain the alternation of the seasons, as has just been done, from the standpoint of the earth, yet, as the matter is of some importance, there will be advantage in considering it also from the point of view of the Sun, which will enable us to realise more clearly some of the conditions on which these changes depend, and will at the same time remove any latent doubt as to the correctness of the conclusions based on a discussion of relative motions, a point of essential importance in the study of astronomy. We arrived at the conclusion that the earth moves round the Sun in a plane orbit inclined to the equator, and that consequently the earth's axis is also inclined. Now this axis always points to the same place among the stars, very near the Pole-star, constantly preserving the same direction during the year. Let us picture to ourselves, then, what would be the appearance presented to an inhabitant of the Sun by our globe during this annual motion. On a round (or slightly oval) table or tea-tray place a night-light a little out of the centre (in the direction of the longer axis of the oval) to represent the Sun's light, and having run a knitting needle through the core of an orange, which will represent the earth and its axis, carry the orange round the edge of the table as the earth moves in the ecliptic, keeping the knitting needle always tilted in the same direction; then if at the same time we keep the orange spinning pretty rapidly, the circumstances of the earth's motion will be represented fairly well, and the flame of the night-light will not be far from the proportionate size of the Sun, as compared with the earth's distance, though the earth ought to be represented by the minutest grain of sand visible to the naked eye, instead of by our orange. But our object being to explain the appearances presented to an observer on the Sun, we must suppose our earth magnified some 1,500 times, as if seen through an exceedingly powerful telescope. The figure represents the arrangement described above, seen from one side, the knitting needle being omitted.

Starting, as before, with the vernal equinox (at the bottom of the picture), when the Sun appears to us on the equator, an observer on the Sun will look at the earth's equator edgeways, and will just catch sight of both poles. As the earth moves on in her orbit, the equator, keeping always the same direction in space, will show its north side more and more to the Sun, until it gets into such a position that all the tilt (southwards) is in the direction passing through the Sun, which corresponds to the solstice (the left of the figure), after which less and less of the tilt is in the Sun's direction, till at length, at the autumnal equinox, the equator is again presented edgeways to the Sun (the top of our figure). During this period the north pole is turned towards the Sun, and the northern hemisphere receives more than its fair share of light and heat, as will be seen by noticing where the boundary of shadow falls on our orange illumined by the night-light. From the autumnal to the vernal equinox the tilt of the earth's equator, as seen from the Sun, will be northwards, and therefore the north pole will be turned away and so receive less light and heat than the south pole, which is presented to the Sun. It is, therefore, winter for the northern hemisphere and summer for the southern. We see at once from this that it is only the distribution of light and heat which varies from this cause, not the total amount. Sometimes the northern hemisphere receives more than the southern, and sometimes the reverse is the case, but this does not affect the common fund. As a matter of fact, the earth does receive more light and heat in January than in July, but this is because she is nearer the Sun at the former epoch; the effect of this on the climate is, however, insensible, being masked by the very much greater changes of the seasons.



THE SEASONS.

It is now time to pay a little attention to the physical constitution of that wonderful body which produces effects of such importance to our well-being. When examined in a powerful telescope, care being taken to diminish the intensity of his heat and light by means of dark glasses, the Sun appears to have a slightly mottled surface, shading off slightly towards the edge, and having usually certain dark markings, called spots, accompanied by streaks brighter than the ordinary surface, and hence called faculæ (torches). If one of these spots be watched from day to day, it will be seen to move across the Sun's disc from east to west, disappearing at the western edge or limb only to reappear after an interval of nearly 14 days at the eastern limb, and cross the Sun's face again in another 13 or 14 days. On extending our observations it is found that all spots move across the Sun's disc in about the same time, although the lengths of their paths differ considerably, and we are therefore led to conclude that their motion is really caused by the Sun's turning round on an axis eastward, or in the same direction as the earth in her orbit, so that it presents the same face to the earth again after an interval of some 27 days. But this is not the true time of rotation of the Sun, for the earth having gone a little way round the Sun in its orbit, the Sun has to turn through a corresponding angle after having completed its rotation, so as to catch the earth up, just as we saw the earth had to do to bring the Sun to the meridian of a place again. Now as the earth goes round the Sun in 365 days, we have, since the times are proportional to the angles turned through, 365+27 : 365 :: 27 : time of Sun's rotation, which, therefore, is rather more than 25 days. As the result of careful measures of the position of spots during their passage across the disc, it is found that they do not move in straight lines except about July 12 and December 11, showing that the circles which they describe, and therefore also the Sun's equator, are tilted with respect to the ecliptic, the plane in which the spectator is, but that we see these circles edgeways (from opposite sides) on the two days given above, just as the equator and circles of latitude on the earth (which are the diurnal paths of spots on the earth) would be seen from the Sun at the vernal and autumnal equinoxes. The tilt of the Sun's equator to the ecliptic appears to be about 7¼°. Now in all this we have something very similar to what we were led to conclude in the case of the earth, and thus the great difficulty of accepting the rapid motion of a mass like the earth is completely removed, for though the Sun's rotation is much slower, yet its mass is enormously greater. It is difficult, indeed, to realise the size of this enormous globe, but some assistance may be gained from the statement that a spot on the Sun's equator moves four times as fast as a point on the earth's equator—*i.e.*, at the rate of 4,000 miles an hour, which is five times the speed of sound, and four times that of a cannon ball—and that with this enormous velocity it takes 25 days to complete the circuit of the Sun. But though we have every reason to suppose that the spots turn round with the Sun, the changes that take place in them show that they are by no means fixtures on his surface, and in fact it is found that one spot has a drift forwards relatively to another, so that they do not all take *exactly* the same time to go round. Their individual movements, however, are small as compared with the motion caused by the Sun's rotation, whilst the changes in their form are most remarkable. Cases have been observed of the formation of a large spot, some 50,000 miles across (six times the size of the earth), in the course of a single day at a part of the surface where nothing unusual was to be seen before; and the disappearance is sometimes equally sudden. Usually a spot does not last more than two or three months, and in this period it will often break up into a group of smaller spots, or such a group may coalesce into one large spot. As a general rule, spots are composed of a central black portion, which is called the nucleus or umbra (shade), surrounded by a less dark part called the penumbra (half-shade), and these two portions are quite distinct, the nucleus lying at a lower level than the penumbra, and both of them below the bright surface which we see ordinarily. That a spot must thus be considered as a hole in the luminous atmosphere of the Sun is shown by the appearance presented on its approach to the limb. We are then looking at the spot obliquely, and it is found that more of the penumbra is seen on the side away from us, whilst on the other side it is very much foreshortened, as we should expect on the supposition that the spot is a hollow with the nucleus at the bottom. An earthenware basin with a little inky water at the bottom will give a rough idea of the appearances thus presented by a spot. Of the causes which give rise to Sun spots little is known, but they appear to be much more frequent about every eleven years, and there is a suspicion that this is due to the influence of the planets.

We must now turn to some other features of the Sun, the red cloud-like prominences, which are seen when the overpowering light of his disc is cut off by the interposition of an opaque body like the Moon, in total eclipses of the Sun, and also by means of a beautiful application of the spectroscope, an instrument designed to determine the nature of the light which comes to us from any bright body. We will briefly explain the principle on which this is founded. Everybody has noticed the colours shown by a glass lustre from a chandelier, and has probably remarked that these colours change as the eye is moved. These effects will be best seen if a lustre be placed on its flat side on a narrow stand, at some distance from and above the flame of a candle, and be viewed by an eye as far off as convenient. The first thing that will be noticed is, that the rays from the candle are bent in passing through the glass, so that in order to see the candle through it, it is necessary for the eye to be placed considerably below the stand. This property of the glass is termed refraction (breaking), and is possessed in a greater or less degree by all transparent substances; it is best seen when the glass is in the shape of a lustre, *i.e.*, a triangular bar, or *prism* as it is technically termed. The next thing to be remarked is, that the flame no longer appears white, but is of a colour which depends on the height of the eye, changing from red to yellow, green, blue, and finally violet, as the head is lowered from the position at which the flame first begins to be seen in the prism. Thus it appears that the white light of the candle is really composed of light of all the colours of the rainbow (a phenomenon caused by a somewhat similar action of the drops of rain on the light of the Sun), and that it may be separated into these colours by a prism of glass which bends the violet rays most out of their course and the red least, the other rays lying between these two. When white light is thus spread out into its component colours, it is said to form a spectrum, and it is to be remarked that though for convenience of explanation we have spoken of red, yellow, green, &c., there is no sharp boundary between two contiguous colours, but that they shade insensibly one into the other, and that corresponding to every degree of bending or deviation there is a certain hue. Now though sunlight, or the light of a candle or gas flame, may thus be spread out into a continuous spectrum, the same is not true of every light; thus burning hydrogen gives out three definite kinds of rays only, corresponding to definite hues of red, greenish blue, and violet. The prominences of the Sun are found to give out light of these three hues exactly (indicating that they also are glowing hydrogen). It is evident that the intensity of the light must be very much enfeebled by the spreading out into a continuous spectrum, or dispersion as it is called, an effect which may be doubled by putting another prism to receive the light after it has passed through the first, so that by making the rays go through a number of prisms one after the other even the direct light of the Sun may be made quite faint, whilst the light of the prominences is scarcely affected, since it consists of three definite hues, each of which is incapable of being spread out. The light which falls on the prisms is usually limited by a narrow slit (perpendicular to the length of the spectrum), and lenses are placed just in front of the first prism, and just after the last, so that the rays of each colour form at a certain distance an image of the slit of this particular hue, and having a corresponding position in the spectrum, which thus appears like a ribbon of shaded colours to an eye placed in a suitable position, and armed with a magnifying lens. Such an instrument is called a spectroscope. If now an image of the Sun be formed on the slit of a spectroscope by means of a large lens, placed so that the slit is directly between it and the first prism, a red image of the prominences will be seen in the corresponding part of the spectrum, when the slit is so placed that it is just outside the Sun's limb, the light of the sky close to the Sun, though bright enough to blot out the prominences when viewed directly, being greatly enfeebled by dispersion into a continuous spectrum. In the same way we may see the prominences by means of the greenish-blue or by means of the violet light which they emit, if we look at those parts of the spectrum respectively. There is thus found to be, outside the surface of the Sun ordinarily visible to us, and known as the *photosphere* (or sphere of light), a layer of glowing hydrogen, to which the name *chromosphere* (sphere of colour) is given from its red hue, and out of this rise strange cloudy masses, sometimes to a height of 80,000 miles, or ten times the diameter of the earth. The chromosphere itself is on the average some 8,000 miles thick, but the thickness varies very much, as its surface is almost always in a state of great agitation, which, when very violent, gives rise to a prominence. Besides hydrogen, there are, in its lower strata, the vapours of many of the metals, of which the presence is revealed in the spectroscope by the characteristic hues of which their light is composed, just as in the case of hydrogen, the hue being determined accurately by the position in the spectrum of the corresponding image of the slit, which will be a bright line of that hue stretching across the spectrum. There is another appendage of the Sun outside the region of prominences which, so far, has only been seen in total eclipses, and which appears on the evidence of the spectroscope to consist chiefly of some substance not yet found on our earth. It extends to an enormous distance from the Sun's surface, perhaps more than a million miles, and appears to be composed of two portions, the term corona being applied to the whole phenomenon from its resemblance to the corona or glory which is frequently seen round the Moon in a hazy sky. The lower portion forms an atmosphere round the Sun, visible as a ring of pale green, and appears to contain hydrogen as well as the unknown substance referred to above; outside this are seen long rays and interlacing plumes which can be traced to a distance of twice the Sun's diameter, with large rifts or gaps reaching nearly down to his limb. This portion appears to shine partly by its own light, and partly by reflected sunlight.

From this account it will be seen that the Sun is made up of a large number of layers, there being below the photosphere, or luminous surface, two or possibly three layers which are exposed to view as the nucleus and penumbra of a spot, and above it the chromosphere, the atmosphere or inner corona, and the outer corona. Besides these there would seem to be a far larger appendage of the Sun, which is seen under favourable conditions (chiefly in the tropics) after sunset, or before sunrise, as a cone of light in the plane of the ecliptic, having the Sun's place as its base. This is called the Zodiacal light, and is now supposed to be composed of myriads of small particles which reflect the Sun's light, and form a lens-shaped disc reaching probably beyond the earth's orbit.

Of the cause of the Sun's light and heat, both of which appear to come almost entirely from the photosphere, no satisfactory explanation has yet been given, and this remains one of the most important subjects of inquiry, the Sun's rays being the immediate source of almost all movements that take place on the surface of the earth, or in its atmosphere.

CHAPTER III.

THE Moon, as will be seen shortly, plays a very insignificant part in the Solar system, but, next to the Sun, it is, from its comparative proximity, the heavenly body of most importance to us. Its motion among the stars is somewhat like that of the Sun, but far more rapid and far more irregular, the Moon taking $27\frac{1}{3}$ and $29\frac{1}{2}$ days to return to the same position nearly with respect to the stars and the Sun respectively, the latter period being longer on account of the Sun's apparent motion (or the earth's real motion) in the interval since the Moon has to overtake the Sun, which is travelling more slowly in the same direction. The former is called a sidereal, and the latter a synodic period or lunation. The determination of the Moon's motion is a far more complicated question than that of the Sun's, but by watching its course among the stars, which can be done much more readily than in the case of the Sun, as moonlight is not sufficient to overpower them, it will be found that the Moon moves in an orbit tilted about 5° to the ecliptic or apparent path of the Sun, the arc described in a day varying from about $14\frac{1}{2}°$ to 12°; while the diameter changes from $29\frac{1}{2}'$ to $32\frac{3}{4}'$, showing that the Moon's distance alters by about one-ninth part. It thus appears that the Moon seems to describe the same sort of path about the earth as the Sun does, but its ellipse is much more oval; it will further appear that the Moon is much smaller than the earth, so that it is natural to suppose that it really revolves round the earth, and not the earth round the Moon. But further observation soon shows that the Moon's motion is not quite so simple as this explanation would lead us to suppose, though it represents the broad facts of the case, and is a fair approximation to the truth. In the first place, it will be found that when the Moon comes back to the ecliptic after having made the tour of the heavens it does not return to exactly the same place on that great circle, but that the point where it crosses is nearly 1° further west, so that the Moon's motion is not really in a plane. It will, however, give us a clearer notion of the path if, instead of supposing the Moon to depart from the original plane, we imagine this plane to be continually shifted so as to follow, as it were, the Moon's movement exactly, the Moon being then always in this shifting plane, which may thus in some sense be considered the plane of its orbit, and this will, at any rate, assist us in realising what the motion actually is. Looking upon this, then, merely as a device to assist us in grasping a difficult subject, we may say that the Moon moves in a plane, inclined about 5° to the ecliptic, and twisting round without altering its tilt at the rate of 1° westward in every lunation, so that it has twisted completely round in 18⅔ years.* Again, when the Moon is observed through several lunations, the point where she is nearest to us, and where her daily motion is greatest, is found to shift eastward by about 3° in every lunation, so that the Moon does not really describe a closed curve, such as a circle or ellipse, though for the reason given above it is convenient to speak of her as moving in an ellipse (or oval), which is continually turning round eastward at the rate of 3° every lunation, completing a circuit within nine years. There are other irregularities which make it necessary to suppose the size and shape of this ellipse variable; so that the Moon's distance from us

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* The plane of the Moon's path may at any instant be determined by supposing it tilted 5° to the ecliptic about a hinge, as it were. The direction of this hinge is called the line of nodes (see fig. p. 59), the nodes being the points where the Moon's apparent path in the heavens crosses the ecliptic. The line of nodes then shifts 1° westward every lunation, going completely round once every 18⅔ years.

changes by more than one-ninth when different lunations are compared, the apparent diameters ranging from 29½′ to 33½′. It may be asked—What is the use of supposing the Moon to move in an ellipse when we have to make continual alterations in its positions and dimensions?—but, in answer to this, it must be remembered that these alterations are small, and that by this way of looking at the subject we are able to consider the irregularities one at a time, instead of being overwhelmed by their mere number. It is by this mode of considering the question that the Lunar Theory, which from a study of the Moon's motions aims at predicting her place at any future time, has been brought to a high state of perfection, a matter of the greatest practical importance to navigation, as the Moon's somewhat rapid motion among the stars enables us at any place to determine the Greenwich time within a few seconds by measuring her distance from certain selected stars, and in this way to determine the longitude (which, as already explained, is simply the difference between the time of the place and Greenwich time), thus fixing a ship's position at sea within a very few miles. In fact the Moon serves the purpose of the hand of a clock which always shows Greenwich time, though the marks corresponding to the minutes are not at equal distances; and the great object of the Lunar Theory is to tell us where these minute marks are to be, in order that the Moon shall always point to true Greenwich time. It is as if, when a clock went wrong from irregularity in its movements, we were unable to alter the hands, and had to make new marks on the dial in order to know the correct time. This question was considered one of such great national importance that the Royal Observatory, Greenwich, was founded by Charles II., in 1675, for the express purpose of watching the Moon's motions; and though careful observations have been made there assiduously for the last 120 years, there are still slight errors in the predicted places of the Moon, though these are of much smaller amount than the uncertainty of measures of the Moon's distance from stars made at sea.

It is now time to give an explanation of the most striking peculiarity of the Moon—her phases. The Sun always appears as a round orb, but not so the Moon. Starting from New Moon, when she is in conjunction* with the Sun, the first appearance presented by the Young Moon, a day or two afterwards, is that of a thin crescent, of which the hollow is turned away from the Sun; the thickness of this crescent gradually increases till it becomes a half-circle at First Quarter, when the Moon is 90° from the Sun; from this point the contour of the side away from the Sun becomes more and more convex, till, when the Moon is almost exactly opposite the Sun at Full Moon, we see a nearly complete circle of light, a very small part of the top or bottom only being wanting, according as she is (from the tilt of her path) below or above the point exactly opposite the Sun. After this the west side begins to wane, and at Last Quarter we have again a half-circle, but with the round side towards the east, the Sun being now on that side; the crescent form now appears again, becoming thinner and thinner as New Moon approaches. Thus from Last Quarter to First Quarter the Moon is crescent-shaped, whilst from First Quarter to Last Quarter she is said to be gibbous, the point to be noticed being that a full circle of light is seen when the Sun is opposite her, whilst we see little or nothing when they are nearly in the same direction. This suggests the idea that the light of the Full Moon is due to the Sun shining directly on her, and that the reason we see nothing at New Moon is that we are then looking at the dark side, the Moon being between us and the Sun. In fact the phases are exactly what we should see in the case of the Sun shining on a dark globe, as may readily be verified by holding a white ball at arm's length

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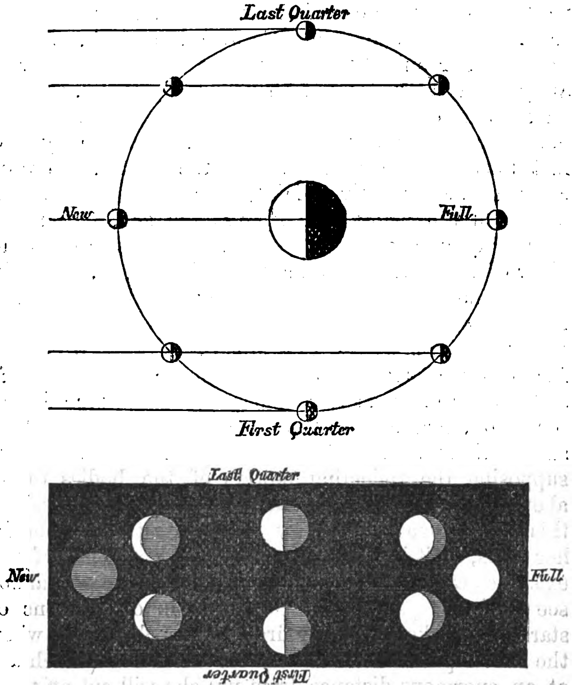
* One heavenly body is said to be in conjunction with another when it has the same longitude, or right ascension, *i.e.*, when it is either in a direct line with the other, or due north or south of it.

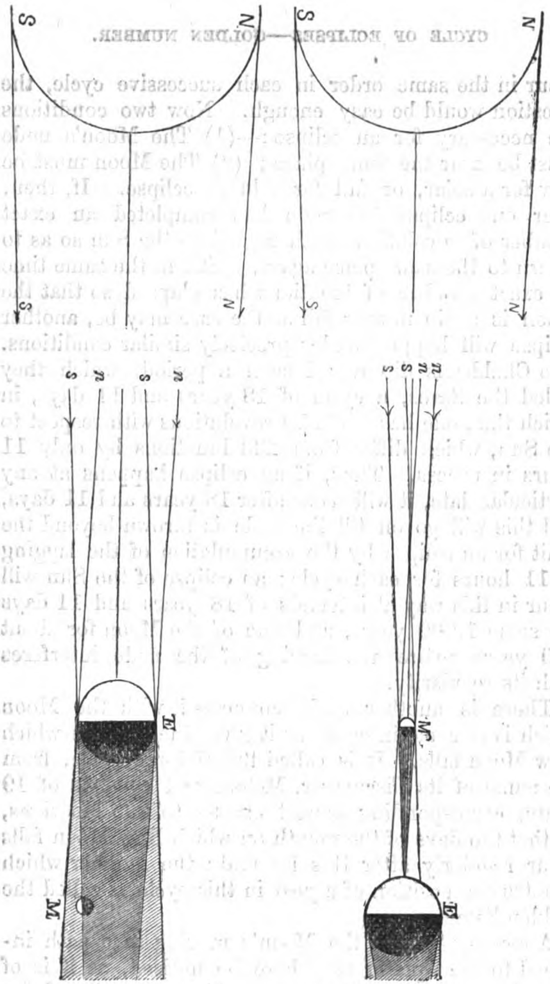
between the eye and the Sun or a light, and slowly turning round with it from right to left. Care being taken that there be no other lights to interfere, it will be found that the ball is always divided into two halves, a bright side turned to the light and a dark side turned



PHASES OF THE MOON.

In the upper figure a bird's-eye view of the Earth and Moon in different parts of her orbit is given, the horizontal lines showing the direction in which the Sun's light falls; the Earth and Moon are each of 12 times their proper size as compared with the orbit. The lower figure shows the corresponding phases of the Moon—the lower part, from New to Full, is to be looked at upside down.

away, and as the ball goes round us, more and more of the bright side comes into view, till at last the whole of it is seen; after this the bright side turns away, and we lose it altogether when the ball comes again to its position between us and the light. It will be noticed that the edge of the ball turned to the light is bright, whilst the opposite edge is dark, and therefore not well seen, and this is just the case with the Moon, the deficient part required to make up the circle being always away from the Sun; but that it really exists, though on account of the overpowering light of the bright portion we generally cannot see it, is shown by the fact that near New Moon, when the light of the thin crescent is comparatively faint, we can readily trace the outline of the whole disc against the sky. There is another circumstance too which contributes to the visibility of the dark portion at such times, viz., that this part of the Moon is illuminated by the light reflected from the earth, just as the part of the earth turned away from the Sun is by the Full Moon; for when it is New Moon to us it is Full Earth to the Moon, and *vice versâ*, and the earth being, as we shall see, four times the size of the Moon, earthlight to the Moon will be something like sixteen times as bright as moonlight is to us, that is, supposing the reflecting powers of the bodies to be about the same, as is probably the case. But besides this appearance of the New Moon with the Old one in her arms, as it is called, we have direct evidence of the existence of the dark part of the Moon, when we cannot see it, in eclipses of the Sun, and in occultations of stars. To take the latter first. It is clear that when the Moon passes between us and the stars (which are at an enormous distance from us) she will cut off their light, so that any star placed in the Moon's course will be hidden or occulted when the Moon passes over it, and this disappearance will, before Full Moon, take place as soon as the eastern or dark part of the Moon's circle comes up to the star, showing that an opaque body having this circular outline is interposed between the star and us; similarly after Full Moon the star does not reappear till it reaches the western edge of the same circle, the bright part being now to the east. It may be remarked here that these occultations of stars afford the most accurate means of determining longitudes where the telegraph is not available, the disappearance or reappearance taking place quite instantaneously, so that the observation may be relied on to a fraction of a second of time. As the plane of the Moon's orbit shifts regularly round once in 18⅔ years, it is evident that in that period the Moon will have occulted at some time or other every star which lies within 5° on either side of the ecliptic, and will, consequently, occasionally pass in front of the Sun, causing an eclipse. This will happen whenever New Moon takes place near the points where the Moon's path cuts the ecliptic (the Moon's nodes); in other cases the Moon will pass above or below the Sun, being tilted out of the ecliptic. If the New Moon takes place exactly at the node she will pass centrally over the Sun, and the apparent diameters of the two bodies being on the average about equal, but each subject to variation through alteration in the distance from us, especially in the case of the Moon, we shall at some central eclipses have the whole of the Sun's light cut off for a few minutes (a total eclipse), and at other eclipses (known as annular) there will be seen just at the middle of the eclipse a ring of light from the Sun round a black circular disc (the Moon). If the Moon when new be not exactly in her node, more or less of the Sun's disc will be cut off, and a partial eclipse will take place; such an eclipse will happen when the Moon's centre appears to pass within the distance of her radius from the Sun's edge, which will be the case when the angular distance from the node is not greater than 17°, or when the passage across the ecliptic is not more than about 1½ days from New Moon. But though an eclipse will, under these circumstances, occur at some place or other on the earth, eclipses at any particular locality are not so common, and total or annular eclipses are exceedingly rare; for a change in the position of a spectator on the earth will throw the Moon out of the direct line between him and the Sun, and thus prevent the Sun from being eclipsed at one place when it is so at another a little north or south of it. There will be no total eclipse visible in this country during the remainder of this century, the next being in A.D. 1927. As the Moon sometimes cuts off the Sun's light from us, so the earth may cut off the Sun from the Moon; when an eclipse of the moon, as we call it, takes place, the appearance being that of the Moon passing into the earth's shadow, and so disappearing, more or less completely, through the Sun's light being cut off; except in so far as it is scattered by clouds in our atmosphere, owing to which effect the eclipsed Moon is usually seen as a dark copper-coloured disc. The Moon's shadow barely reaches to the earth in an eclipse of the Sun, and, under the most favourable circumstances, throws a black spot on the earth not more than 120 miles in diameter; but the earth being four times the size of the Moon, her shadow reaches far beyond the Moon's orbit, and is at the distance of the Moon about two-and-a-half times the Moon's diameter. If the Moon when full be near enough to her node to pass within this shadow, an eclipse will take place, and this will happen whenever the distance from either node at opposition is less than $10\frac{3}{4}$°, or when Full Moon occurs within 20 hours of the passage across the ecliptic. Unlike an eclipse of the Sun a lunar eclipse is visible at any place for which the Moon is above the horizon, *i.e.*, on the hemisphere turned towards the Moon and away from the Sun, the position of the spectator not affecting the entry of the Moon into the earth's shadow. From the earliest times eclipses forced themselves on the attention of mankind, having in one notable instance (the eclipse predicted by Thales) put an end to a war between the Medes and Lydians, as related by Herodotus, so that a method of predicting them was eagerly sought for. If only a cycle of years could be found, such that eclipses would



ECLIPSES OF MOON AND SUN.

The Sun ought to be removed to nearly 400 times the distance M E, and to be 2⅔ times as large. The Earth and Moon are 12 times their proper size.

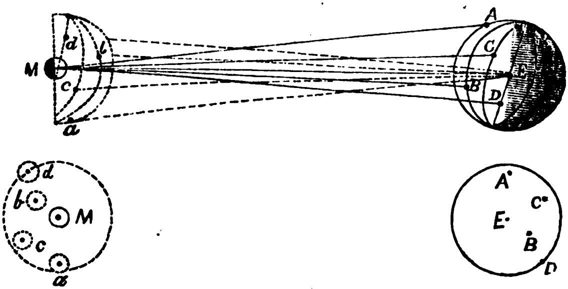
recur in the same order in each successive cycle, the question would be easy enough. Now two conditions are necessary for an eclipse:—(1) The Moon's node must be near the Sun's place; (2) The Moon must be new for a solar, or full for a lunar eclipse. If, then, after one eclipse the node has completed an exact number of revolutions with regard to the Sun so as to return to the same place again, whilst in the same time an exact number of lunations has elapsed so that the Moon is again new or full as the case may be, another eclipse will happen under precisely similar conditions. The Chaldeans discovered such a period, which they called the Saros, a cycle of 18 years and 11 days, in which the node has made 19 revolutions with respect to the Sun, which differ from 233 lunations by only 11 hours in excess. Thus, if an eclipse happens at any particular date, it will recur after 18 years and 11 days, and this will go on till the node is thrown beyond the limit for an eclipse by the accumulation of the lagging in 11 hours for each cycle; an eclipse of the Sun will recur in this way at intervals of 18 years and 11 days for some 1,000 years, and one of the Moon for about 800 years before the lagging of the node interferes with its regularity.

There is another cycle connected with the Moon which is of some interest, as it gives the days on which New Moon falls. It is called the Metonic cycle, from the name of its discoverer, Meton, and consists of 19 years, corresponding almost exactly to 235 lunations, so that the days of the month on which New Moon falls recur regularly after this interval; the number which denotes the position of a year in this cycle is called the Golden Number.

A consequence of the Moon's moving in a path inclined to the equator may here be noticed, as it is of some importance to the farmer. From the tilt of the ecliptic the Moon's motion in her orbit is inclined to the equator, and is partly eastward and partly north or south. When she is in that part of the ecliptic where the Sun is at the vernal equinox, her motion northwards is most rapid, and in high northern latitudes is nearly parallel to the horizon, so that her motion eastwards, which tends to make her rise later, is compensated by the northward part of her motion, and consequently she will in that part of her path rise at nearly the same time on two or three successive nights, and this will happen once in every lunation. There is a special importance, however, in this phenomenon, when the Full Moon falls at this part of the orbit, for then the Moon rises for several days just at sunset, and thus gives light enough to get in the harvest, whence this is called the Harvest Moon. As in this case the Moon is full at the vernal equinox, the Sun, which is exactly opposite, must be at the autumnal equinox, so that the Harvest Moon is that Full Moon which is nearest to September 21. In England the harvest is usually over a month before this, but in many countries this lengthening of the day by the Harvest Moon is of great value.

The Moon's distance from the earth has been very accurately determined by a method founded on the fact that as an observer moves forwards, objects on either side of him appear to move backwards with a rapidity proportional to their distances from him, an effect which is well seen from a railway carriage in motion, the trees and houses in the landscape appearing to wheel about a point in the extreme distance on either side as a pivot. For every yard that the train advances every object will appear to move a yard backwards, so that each object is shifted apparently through the angle, subtended by a yard at the distance of the object, which explains the slower apparent motion of the more distant objects. By measuring, then, the angular shift of any object, we determine the angle under which a yard appears at the distance of that object, and hence readily the distance itself. For an arc of $57\frac{3}{10}^\circ$ is equal to the radius of the circle (the circumference of 360° being $3\frac{1}{7}$ times the diameter), whence we have only to divide the angle we measure into $57\frac{3}{10}°$ to find how many times the radius contains the arc, which, in the case we are considering, is one yard; the number of times so found will, of course, give the distance in yards. It is not necessary that the spectator move in an arc of a circle about the object as centre, for in dealing with small angles the arc is very nearly a straight line, and the difference is easily allowed for where accurate calculations are made.

Now let us apply this principle to the case of the Moon, remembering that the distances we are here concerned with are very large, and that we have to deal with thousands of miles in the place of yards. Suppose two spectators at the extreme north and south of the hemisphere visible to the Moon, which is, therefore, on the south horizon in the one case and on the north horizon in the other. The southern observer will see the Moon shifted north among the stars (which are too far off to be so affected) through an angle equal to the angular diameter of the earth seen from the Moon, and the part that this angle is of $57\frac{3}{10}°$ gives the fraction that the earth's diameter is of the distance of the Moon, so that, having the diameter of the earth, the Moon's distance is easily found in miles. But in practice it would not be very easy to make observations at two such stations as we have supposed, and it is found better to be satisfied with a rather less shift in order to have the Moon at a sufficient altitude at both stations to get rid of the uncertainties of refraction near the horizon. The observatories which have been used for this purpose are those of Greenwich and the Cape of Good Hope, at both of which the Moon is observed with the utmost regularity every day that she is visible; so that a large number of observations are available, the average of which will give a very accurate result. The mode of determining the Moon's distance by observations at these two stations is not quite so simple as in the ideal case given above, but the matter may be made clear by the following consideration. From every point of the earth's surface the Moon is seen in a different position, so that by plotting down corresponding places of the Moon's centre among the stars, we shall have a representation of the points of the earth's surface as seen from the Moon, the apparent shift of the Moon from its central position being, as already stated, equal to the apparent distance of the corresponding station from the centre of the earth's disc as seen from the Moon: this is called the Moon's parallax, being the difference between her direction as seen at the given place and at the earth's centre, and is evidently greater for points round the edge of the earth's disc than for those within; for the former the Moon is at the given instant on the horizon, and the shift of her apparent position is then called horizontal parallax. The earth's disc as seen from the Moon not being perfectly circular on account of the bulging out of the equator, the horizontal parallax will be greatest at the equator, since the two points where the equator meets the edge of the disc are further from the centre than any others; this value is called the Equatorial Horizontal Parallax. It will, of course, be understood that on account of the



PARALLAX OF THE MOON.

The left hand figures show the positions of the Moon as seen from five stations on the Earth; the lower figures give the Earth's disc seen from the Moon and the imaginary disc marked out by the Moon as seen from different places of the Earth, but reversed right for left, as if looked at from outside a celestial globe.

earth's rotation the disc visible to the Moon is continually changing, and that, consequently, the parallax at any place changes as the Moon rises or sets. The Moon being in the zenith of the place at the centre of the disc, the parallax is nothing for that position of the Moon, and increases as she moves towards the horizon. Now when the Moon is on the meridian of Greenwich, it is easy, from her observed zenith distance, to calculate what part the apparent distance of Greenwich from the middle of the earth's disc, as seen from the Moon, is of the diameter of that disc, and, again, when the Moon is on the meridian of the Cape Observatory, the corresponding fraction in that case; so that by adding these two fractions together the proportion of the apparent shift in the case of Greenwich and the Cape to the shift for the two extremities of a diameter is obtained. The shift corresponding to Greenwich and the Cape is obtained by observing the Moon's meridian distance, as compared with those of selected stars at both observatories, or, in other words, the shift of the Moon with respect to stars near, allowance being made for the Moon's motion in declination in passing from the meridian of Greenwich to that of the Cape. In this way it is found that the shift for two extremities of an equatorial diameter is 1° 54′, which is, therefore, the diameter of the earth's disc at the Moon's average distance; so that the equatorial horizontal parallax is 57′. The Moon's distance is therefore (since $57\frac{3}{10}^{\circ}$ is about 60 times 57′), about 60 times the earth's radius at the equator, or 30 times its diameter, making it about 239,000 miles. Since the Moon's apparent diameter at her mean distance is about 31′, while that of the earth is 1° 54′, it follows that the real diameter of the Moon is rather more than one-fourth that of the earth, being very nearly 2,160 miles. We may now get a tolerably clear idea of the motion of the Moon about the Sun, for we see that while she is moving round the earth at a distance of 60 times the earth's radius in a lunar month, the earth is moving round the

Sun at 385 times this distance (232,000 times the earth's radius) once a year, and carrying the Moon with her. Thus if a circle, or more strictly an ellipse, be drawn of four inches radius to represent the path of the earth round the Sun, the Moon's motion round the Sun will be represented by dividing the circumference into 13 parts about; and supposing the Moon at these 13 points corresponding to New Moon to be $\frac{1}{100}$ inch inside the middle of the line representing the circumference, and at intermediate points corresponding to Full Moon to be $\frac{1}{100}$ inch outside, so that the excursions of the Moon will all be contained within the breadth of the pencil line which marks the circumference and the deviation of her path from a true circle (or nearly circular ellipse) about the Sun would be quite unappreciable to the eye on such a scale. It may seem strange that we should speak of the Moon describing an ellipse round the earth when she really moves very nearly in a circle about the Sun, but in explanation of the apparent anomaly it is sufficient to remark that the earth is dragging the Moon with her round the Sun at the rate of 18 miles a second, whilst the Moon's motion round the earth is only $\frac{6}{10}$ of a mile in the same time, so that even when the Moon's motion round the earth is in the opposite direction to that in which she is carried by the earth's motion round the Sun, which is the case at New Moon, the Moon is still moving round the Sun in the same direction as the earth, and with a velocity only about $\frac{1}{30}$ less. Thus we may consider the Moon as describing either an ellipse about the earth or an almost circular oval about the Sun, according as we take the earth or the Sun as our standpoint; both modes of expression are correct, provided we remember that the motion is in both cases relative, and that for anything we know the Sun itself may be moving round some far distant centre even more rapidly in space than the earth is round the Sun, so that the earth and the Moon too may really be describing nearly circular paths round this distant orb, a supposition which we have some reason to consider probable. However this may be, we can commit no error in considering the Moon to move round the earth, and both earth and Moon to move round the Sun in nearly circular paths, so long as we confine ourselves to the relative motions of these three bodies, without reference to any real (as distinguished from apparent) motions they may have among the stars.

There is one peculiarity of the Moon which strikes every one who watches her disc through a telescope—it is this, she always presents the same face to the earth as she circulates round it. Now this can only arise from her turning round on her own axis in exactly the same time as she turns round the earth, though at first sight it may seem a little difficult to see how she can be really rotating, when she does not show any signs of it to us. A little consideration of what was said in the last chapter on the relative motion of two bodies will remove this difficulty. It was there pointed out that, as far as the two bodies are concerned, the appearances would be exactly the same to a spectator on either the earth or the Sun, whether the earth went round the Sun or the Sun round the earth, and that so long as we were dealing with those two alone it was only a question of convenience which expression we used. Now the same principle applies to the earth and Moon; so that, so long as we are considering the Moon's appearance to us, and not her motion among the stars, we shall have the same result by supposing the earth to be moving round the Moon, as in the actual case. But if the earth be turning round the Moon, it is evident that, for the same face to be always seen by the earth, the Moon must turn on her own axis exactly at the same rate as the earth turns round her, that is, once in $27\frac{1}{3}$ days. To represent the Moon's motion round the earth we must suppose the earth to turn round the Moon sometimes faster and sometimes slower, so that she is alternately in advance of and behind what we may call her proper place, just as in the case of the Sun; the Moon, on the other hand, turns quite uniformly on her axis, and the earth in consequence gets to see a little more round one side at one time and a little more round the other side at another, through her outstripping or lagging behind the Moon in her turning.

The Moon being such a very near neighbour of ours, as compared with other heavenly bodies, her surface has been studied with great success by means of powerful telescopes, and careful charts have been made in which the positions of all the principal markings on her visible disc are laid down with an accuracy surpassing that of most terrestrial maps. With a magnifying power of 500 the Moon may, with a powerful telescope and exceptionally clear state of our atmosphere, be brought apparently within about 500 miles, a distance at which the principal features of a country would readily be made out. Fortunately for the study of her surface she appears to be quite destitute of any appreciable atmosphere, no trace of refraction being perceived when the rays from a star graze her surface just before an occultation, and no signs of water or vapour being visible on her disc. This absence of atmosphere exposes the Moon to most violent changes of temperature, the surface being heated during the long lunar day of half a month to the melting point of iron, and cooled during the next fortnight to the temperature of space, 460° below zero of Fahrenheit's scale, or further below the freezing point than the melting point of iron is above it, a condition of things which would of course be fatal to any form of life with which we are acquainted.

The Moon's surface almost everywhere shows signs of violent volcanic action far exceeding anything found on the earth, the most conspicuous features being the craters, which are found of all sizes, from eighty miles across down to the most minute speck visible, crowded together so closely in many regions that they overlap each other. The great peculiarity of these lunar craters is that the floor inside is nearly always at a far lower level than the outside surface, as may be shown by measuring the lengths of the shadows cast by the rampart round the crater on the floor and on the surface of the Moon outside. From such measurements it is easy, when the elevation of the Sun is found (from the angular distance of the crater from the illuminated edge) to determine the height of the rim of a crater or of a mountain, and in this way the altitudes of a large number of objects on the Moon have been obtained. Although the Moon is only a quarter the size of the earth, there are both craters and mountains rivalling in height the most elevated peaks on the earth; nor is this to be wondered at, for we have no reason to suppose that the force of volcanic energy is less for a small planet; whilst gravitation on the Moon, which draws heavy bodies downwards, and so counteracts the force of upheaval, is only a sixth of what it is on the earth; so that we should expect cinders to be projected from lunar volcanoes to a much greater distance than is the case on the earth, a supposition fully borne out by the large size of many of the craters on the Moon. Though both craters and mountains are found on the Moon, the former are far more frequent, there being only three principal ranges of mountains, called respectively the Alps, the Caucasus, and the Apennines, the Moon in this respect presenting a marked contrast to the earth. The mountain ranges are all three situated in the north, whilst the southern portion of the Moon is remarkable for its large number of craters, the most conspicuous of which, Tycho, seems to form a centre of eruption, from which proceed in all directions bright rays, extending in some cases to a distance of 600 miles. This crater is over fifty miles in breadth and some 18,000 feet in depth, with a central cone 5,000 feet high, and with its system of radiating streaks is distinctly visible to the naked eye about Full Moon. Similar systems of bright rays proceed from several other craters, among which may be mentioned Copernicus, which is well seen near the middle of the boundary of the bright part of the Moon a day or two after the first quarter, and Aristarchus, which first comes into view as an exceedingly bright spot in the north-east two or three days before Full Moon. The first idea that suggests itself with reference to these rays is that they are streams of lava flowing from the craters, but a fatal objection to this explanation is that they pursue their course over hill and dale, regardless of the obstacles in their path, and can actually be traced across the floors of craters which must have been formed before this eruption, the way in which one crater overlaps another affording an indication of its relative age. The most plausible explanation offered as yet seems to be that the rays are cracks, like stars in ice, caused by the eruptive force which formed the crater, and covered over by the lava which has exuded from them, just as radiating streaks are formed in a sheet of ice by the freezing of water which comes through the cracks. It remains to mention the so-called seas on the Moon, which are apparently nothing but dark grey plains composed of materials which reflect less light than other portions, and which from their size are sufficiently conspicuous to the naked eye, especially at Full Moon, when the markings present some resemblance to a human face. Though the term sea conveys a false impression of the nature of these plains, there being a total absence of water on the side of the Moon turned towards us, the term is still retained to avoid the confusion which might be caused by introducing a new nomenclature, the "seas" being named from supposed qualities, *e.g.*, Mare Imbrium, Mare Nubium, and the craters and mountains from celebrated philosophers.

CHAPTER IV.

HAVING discussed the motions of the Sun and Moon, we shall now be better prepared to study the far more complicated movements of the planets. The planet Venus, which is so conspicuous as a morning or evening star at different parts of her course, will serve as the best introduction to the question. Suppose, then, we watch this planet when she first appears as an evening star, setting soon after the Sun; it will be found that her angular distance from the Sun increases day after day, till after seven months she arrives at a turning point nearly 47° from the Sun, after which she begins to approach him again, and after another two months is again lost in his rays at sunset. All this time, if watched through a telescope, her diameter will appear to increase gradually to six times its original value, whilst she goes through phases like the Moon, from nearly full when first seen, to a fine crescent at her disappearance in the evening twilight. After a short interval she may be again picked up, but this time as a morning star, just before sunrise, and continued watching will show that her distance west of the Sun increases for nearly seven months, as her distance east did before, and that after reaching 47° it diminishes for the next two months, till she is again lost in the Sun's rays to reappear east of him, the phases and changes of diameter corresponding to those seen when she was an evening star. These movements may be watched more closely with a telescope, which enables us to see the planet in broad daylight if we know whereabouts to look; the best way of fixing the position will be to observe with a transit-circle the time of transit and the meridian altitude of the planet, the corresponding quantities being also determined for the Sun, so that the right ascensions and declinations of both bodies are found, and therefore their relative position. From a consideration of the motions above described it appears that Venus moves in some way about the Sun, never getting very far from him, and that she is more than six times as far from us when she changes from a morning to an evening star than in the opposite position. Again, her phases show that when nearest, or in inferior conjunction, she is between us and the Sun, as the Moon when new, whilst when furthest off, or in superior conjunction, she is beyond the Sun, so that we see the side lighted up by him; for, as in the case of the Moon, we may conclude that Venus shines by light reflected from the Sun, though she is never seen in the quarter of the heavens opposite to the Sun, as is the case with the Full Moon. It follows from all this that Venus describes a smaller orbit round the Sun than the earth does, and that consequently she is always inside the earth's path; the time she takes to complete a revolution with respect to the earth is 584 days, or 1⅗ years nearly, in which period she must have made 2⅗ revolutions relatively to the stars, having gained exactly one revolution on the earth; so that the time of one sidereal revolution is found by dividing 1⅗ years by 2⅗, and is, therefore, $\frac{8}{13}$ of a year, or 224 days about (more exactly 224·7 days), which is somewhat over 7 months. The determination of the exact path described by Venus is a more complicated matter, since it is necessary to find from observations made on the earth her positions as seen from the Sun, but when this is done it appears that, like the earth, she describes an ellipse round the Sun, having a tilt of nearly 3½° to the earth's path. Since Venus is six times as far from us in superior conjunction as at inferior, it follows that the diameter of her orbit, which is the difference between these two distances, must be five times her least distance from us; so that her distance from the sun is about 2½ times and the earth's distance is 3½ times the distance of Venus from us when nearest, thus her distance from the Sun is 2½ divided by 3½, or about $\frac{5}{7}$ of the earth's distance from the Sun. The same result may be arrived at by observing her greatest angular distance from the Sun (or elongation as it is termed), in the same way as the breadth of a round tower may be found by observing the angle under

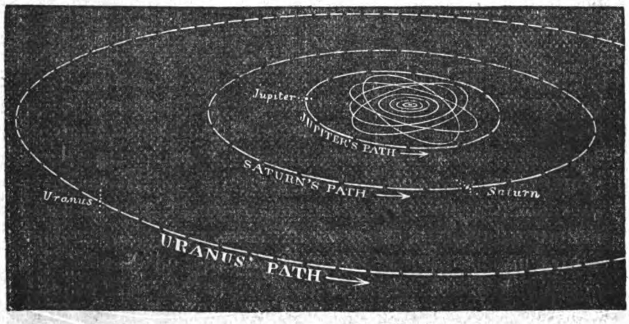
TILT OF ONE ORBIT TO ANOTHER, SHOWING LINE OF NODES.

which it appears at a known distance from its centre. We shall see presently how the relative distances of the planets may be determined more accurately indirectly by means of their times of revolution, or years as they may be called.

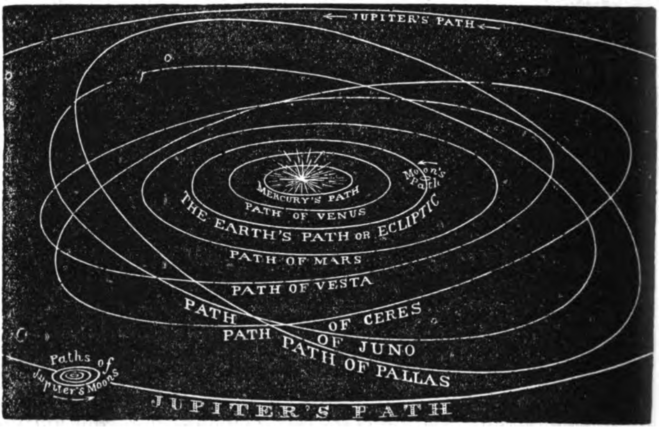
There is another planet, Mercury, whose motions are similar to those of Venus, though he is much closer to the Sun, and can only be seen under favourable circumstances, when his angular distance is greatest, either as an evening or morning star. This planet goes through all its phases in four months (nearly 116 days), whence it follows, by the same reasoning as in the case of *Venus*, that its year is three months (more exactly 88 days); the distance from the Sun varies much more than is the case with Venus or the earth, Mercury's orbit being much more oval. His distance from the Sun is about $\frac{2}{5}$ of that of the earth, subject to an increase or decrease of one-fifth of its mean value, which causes a change in the greatest elongation from 16° to 29°, so that there is much more irregularity in this planet's motions than in the case of Venus.

Mercury and Venus are called inferior planets as their orbits are within that of the earth; the other planets exhibit motions of a different character, not being limited to a certain distance from the Sun, but, moving westward from him continually, they arrive at the opposite quarter of the heavens; after which, still moving westward with respect to the Sun, they begin to approach him on the eastern side; so that instead of oscillating about the Sun as the inferior planets appear to do, these superior planets, as they are termed, make a complete circuit of the heavens in an easterly direction with reference to the Sun, the result of the Sun's apparent motion eastward being more rapid than that of these planets, in consequence of which they lag behind him; though their motion among the stars is, on the whole, eastward like the Sun's, but slower, and with periods of movement in the opposite direction at certain intervals. To fix our ideas let us take the case of the planet Mars.

Starting from conjunction with the Sun, Mars will appear as a morning star, rising earlier and earlier (by solar time) every day till he comes to opposition, at which time he passes the meridian at midnight, exactly opposite to the Sun, and is visible all night; continuing the same course he now rises before sunset and sets before sunrise, and thus becomes an evening star, which he continues to be until his westward course with respect to the Sun brings him so near the Sun's direction that he sets almost at the same time, and is thus lost in his rays. The period of these changes is two years and two months nearly, during which time the earth has gained one revolution on Mars, as he has been continually lagging behind the Sun in his apparent yearly round, so that Mars must have made $1\frac{1}{6}$ revolutions in $2\frac{1}{6}$ years, whence his year is $\frac{13}{7}$ of ours, or more accurately 687 days. All this time he has presented to us a full, or nearly full, disc, so that we must always be looking at the same side as the Sun does, and he can never be between us and the Sun, as is the case with an inferior planet; whence it follows that Mars describes an orbit about the Sun (which extended observations show to be somewhat oval, the greatest and least distances from the Sun being in the proportion of 9 to 11), and that this



orbit is altogether outside that of the earth. The diameter of Mars is five times as great in opposition as in conjunction, while in the latter position he is further distant from us than in the former by the breadth of the earth's orbit, which is therefore four times his distance from us at opposition. From this it follows that the earth's distance from the Sun is twice her distance from Mars when we are in a line between him and the Sun, whence the distance of Mars from the Sun is three times his least distance from us, or 1½ times our distance from the Sun. The motions of the other superior planets are generally similar. Jupiter's year is nearly twelve of ours, the intervals between successive oppositions being nearly a twelfth part more than a year, or thirteen months; his distance from the Sun is rather over five times that of the earth, so that his distance from us only varies from four to six times the earth's distance from the Sun. The intervals between successive oppositions for Saturn are only a fortnight over a year, in which time he must have described one-thirtieth of



his revolution, whence his year is nearly thirty of ours, and his path round the Sun is described at a distance 9½ times as great as that of the earth. These were all the planets known to the ancients, but two more have been added since—one of which, Uranus, discovered by Sir W. Herschel in 1781, is at 19 times our distance from the Sun, and has a year more than 80 times as long as ours; the other, Neptune, was discovered through its attraction on Uranus; it is 30 times as far from the Sun as we are, and its period is 160 of our years.

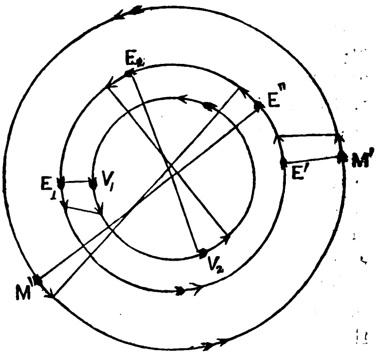
Besides these there is a class of bodies called Asteroids, or minor planets, the first of which was discovered on the first day of this century; about 150 of them have been detected up to the present time, and every year adds several to the list. These bodies are as minute as they are numerous; probably none of them exceed 200 miles in diameter, whilst some are not much more than 10 miles. Their orbits all lie between those of Mars and Jupiter, at distances ranging from 2½ to 3½ times that of the earth, with periods of from 3 to 6 years. Some of their paths are very oval and much inclined to the earth's orbit, presenting a marked contrast in this respect to the large planets, especially the outer ones. These asteroids seem to form a connecting link in the gradation from the large and widely separated planets to the smallest meteors, which perhaps constitute the zodiacal light, and form the tails of comets. The idea has been advanced that these small bodies, so different from the principal planets, may perhaps be the result of an explosion which has shattered a planet formerly circulating round the Sun in an orbit between those of Mars and Jupiter, and scattered the fragments in various directions. Though this theory would account for the peculiarities of these minute planets, the necessity for making any such supposition is to a great extent removed by the discovery of systems of much smaller bodies, the meteors, revolving round the Sun; and there remains the great difficulty in accepting it, that the asteroids, having all started from the place of explosion, must in their course round the Sun all return to it, so that all their orbits ought to have some common point of intersection, which is not only not the case now, but, as far as we can judge from theory, never could have been true unless the present orbits have been disturbed by some unknown cause.

Thus far we have confined our attention to the apparent motions of the planets with respect to the Sun so as to present the subject in its simplest form; by allowing for the motion of the Sun among the stars it will not be very difficult to find that of the planets. The first point of which we must take account is that, since they move nearly uniformly in circles about the Sun, they will appear to move faster with reference to the Sun when they are near us. It is further necessary to distinguish between inferior and superior planets: the former oscillate about the Sun, moving sometimes eastward sometimes westward to or from him; the latter move round and round always westward, as explained above. Taking any inferior planet at superior conjunction, the planet is moving eastward from the Sun, and the Sun is moving eastward among the stars, so that the planet's motion among the stars is eastward, or direct as it is called; this will continue till the planet has turned, and its motion towards the Sun has become equal to the Sun's motion among the stars, when for the moment it will be stationary among the stars, after which the planet's apparent motion towards the Sun will become more rapid as it gets near the earth, and moving faster westwards towards the Sun than the Sun does among the stars, its motion among the stars will also be westward, or retrograde. This will always be the case at inferior conjunction, for the several planets move more quickly the nearer they are to the Sun, the time they take to complete their circles decreasing more rapidly than the size of those circles as we go from the outer planets to the inner; thus Venus takes $\frac{8}{13}$ of the time taken by the earth, but her circle is $\frac{5}{7}$ of that of the earth, which is a larger fraction than $\frac{8}{13}$ ($\frac{5}{7}$ is equal to $\frac{65}{91}$ and $\frac{8}{13}$ to $\frac{56}{91}$). The velocities of the different planets are given in the table at the end.

Let us now take the case of a superior planet. In conjunction its motion westward with respect to the Sun is less than the Sun's motion eastward, so that its resulting motion among the stars is eastward, or direct, just as in the case of an inferior planet. As opposition is approached the motion westward with respect to the Sun increases till it becomes equal to the Sun's eastward motion, when the planet is for the moment stationary among the stars, after which, the westward motion still increasing, the planet will move among the stars in a westward or retrograde direction.

These may be taken as the results of observation, but it is desirable to explain how they follow from the motions of the planets in their orbits with the velocities given above. At superior conjunction, whether for an inferior or superior planet, the earth and the planet are on opposite sides of the Sun, and are therefore moving in opposite directions, so that the earth's motion makes the planet appear to move faster eastward, the effect of a motion of the spectator being, as explained before, to make objects appear to move in the opposite direction. At inferior conjunction for an inferior planet, or at opposition for a superior, the earth and the planet, being on the same side of the Sun, are moving in the same direction; in the case of an inferior planet the planet's motion is greater than that of the earth, and is westward, as seen from the earth, which is outside the orbit, in the same way as Sun-spots as seen from the earth move from east to west, though the Sun's rotation is, like the motions of the planets, eastward. From this it results that at inferior conjunction the planet appears to move westward as if it had a velocity equal to the difference between its actual velocity and that of the earth; this would be for Mercury about 11 miles, and for Venus about 3 miles in a second.

In the case of a superior planet in opposition the earth's motion makes the planet appear to travel westward faster than the planet actually moves eastward in its orbit, so that the apparent motion among the stars is westward, Mars seeming to move with a velocity of 3¾ miles in a second, Jupiter with a velocity of 10 miles, Saturn of 12 miles, Uranus of 14, and Neptune of 15, being the difference between the earth's velocity and that of these several planets in their orbits. Of course in intermediate positions between conjunction and opposition, or superior and inferior conjunction, we shall have intermediate motions, the apparent movement being in every case retrograde for a greater or less arc about inferior conjunction or opposition. It may at first sight seem strange that the earth's motion should at the same time make an inferior planet at inferior conjunction and a superior planet in opposition appear to move in opposite directions, but this is readily explained by the circumstance that the planets in the two cases are on opposite sides of us, it being understood that east and west merely refer to the sense in which a planet turns, a westward motion being in the same direction as the Sun's daily motion from its rising in the east to its setting in the west; so that the east and west parts of any orbit simply depend on the point from which we are looking at it, the east being to our left and the west



CONJUNCTION AND OPPOSITION OF VENUS, THE EARTH, AND MARS.

The arrows show the motions of the several planets in equal times.

to our right as we look south, and just the opposite as we look north.

Since Mercury and Venus pass between the earth and the Sun at inferior conjunction they will sometimes cause partial eclipses, though from their small apparent size the amount of light they cut off, when directly between us and the Sun, is hardly appreciable, these planets passing over the Sun's disc as small round black spots, on account of which these phenomena are not called eclipses but Transits (*i.e.*, passages). Just as in the case of eclipses caused by the Moon, such transits will only occur when the planet is near one of its nodes; now if Mercury be in its node at one inferior conjunction, when it next comes to inferior conjunction Mercury will have made $1\frac{1}{3}$ revolutions, and the earth a third of a revolution about, so that it will be far from the node of Mercury's orbit, and the planet therefore out of the direct line between the earth and the Sun. Next time the earth will have moved through two-thirds of a revolution from the first position, and at the third conjunction will have returned nearly to the same point of its orbit, having completed very nearly one revolution; if it had done so exactly there would be another transit, but after three inferior conjunctions the earth has still about $\frac{1}{21}$ of a revolution ($17\frac{1}{4}$ days) to go, and is therefore too far from the node; after another three conjunctions it will be $\frac{2}{21}$ of a revolution short, and so on, until after 21 conjunctions it has fallen a third of a revolution behind the starting place, so that the next conjunction brings it very near the node again (within one day about), Mercury having completed 29 revolutions in 7 years very nearly, and another transit may now take place. The return to the node would fall between the sixth and seventh years, so that after 13 years there is a more exact return, and transits generally happen after this interval, though the eccentricity of Mercury's orbit introduces considerable irregularity into these periods. All this refers to one node only, at the other there will be another series of transits.

In the case of Venus, whose year is $\frac{8}{13}$ of ours, the return to the node will take place very nearly after 8 of our years or 13 of those of Venus, Venus being then only $1\frac{1}{2}$ days from node may again transit the Sun, but after another 8 years she will be 3 days off, and the tilt of her orbit taking effect, no transit will occur; nor will one take place again till after 235 years, when the error of $1\frac{1}{2}$ days of the motion of Venus in every 8 years has amounted to one-fifth of 225 days, so that another of the five conjunctions which take place in eight years at different parts of the orbit of Venus will now fall at the node. The ascending node of Venus is in a line with the earth at the beginning of December, and transits have taken place in that month in 1631, 1639, and 1874, after which there will be another in 1882; at the descending node the transits, which occur always in June, are those of 1761, 1769, 2004, and 2012. Transits of Venus are of the greatest value to the astronomer for the means which they afford of determining the Sun's distance, and thus fixing the scale of the whole solar system. The distance of the Sun is so enormous as compared with any base line we can get on the earth, that his parallax cannot be determined with sufficient accuracy by the method used for the Moon; but as the planet Venus, when nearest, is only $\frac{2}{7}$ of the Sun's distance the parallactic shift will be $\frac{7}{2}$, or $3\frac{1}{2}$ times that of the Sun; even this quantity is very small, and instead of attempting to determine it directly it is better to find the shift of Venus relatively to the Sun. This is a slightly different problem from the other, for in this case we only determine how much more Venus is shifted than the Sun, and not the absolute shift of either. When two bodies at different distances are seen on the same straight line the nearer appears to be shifted relatively to the other by a shift in the spectator's position, but in the opposite direction. If each body be removed to twice its distance from the spectator, thus keeping the distances in the same proportion, the amount of this shift will be halved, whilst if they be each brought to half their original distances it will be doubled. If then the proportion of these distances be known, the shift or parallactic displacement will enable us to determine both the distances. Now in the case of Venus and the Sun the proportion of the distances can be found with the greatest accuracy by means of the periods of revolutions of Venus and the earth, as will be explained shortly, the approximate ratio found from the changes in the diameter of Venus being $\frac{2}{7}$. Thus the shift of Venus being 3½ times that of the Sun, her shift relatively to the Sun will be 2½ times the same quantity. The most accurate way of measuring the very small quantity we are dealing with is to refer it to the very slow motion of Venus in her passage across the Sun's disc, by noting at two stations widely apart the exact instant at which that planet is seen to enter wholly on the Sun's disc, or to begin to leave it. In order that parallax may produce its greatest effect, on the time of ingress, the shift must be perpendicular to the Sun's limb where Venus enters, and therefore the two stations should be separated from each other in the direction of a line joining this point with the Sun's centre.

In the transit of 1874 Venus crosses the northern part of the Sun's face obliquely in a north-west direction, and Australia is nearly in the middle of the hemisphere which is turned towards the Sun at ingress, whilst the Indian Ocean occupies that position at egress some 3½ hours later. The best stations for ingress will therefore be in the North Pacific and in the Southern Ocean, about 10° due south of the Cape of Good Hope, and for egress in Siberia and on the Antarctic continent.* The greatest shift would be produced when the Sun is at opposite points of the horizon for the two stations;

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* The explanation given in the case of the Moon's parallax, with the accompanying figure, on page 51, will assist the reader in understanding this clearly. In the lower left-hand figure, *d* will represent Venus at egress on the Sun's disc reversed, *i.e.*, as she would be seen from the other side of the Sun, if it were transparent and we looked through it.

but as in that case we could not see the phenomenon well on account of the low altitude of the Sun, the stations must be so chosen that the Sun is sufficiently high and yet that the parallactic shift is considerable.

In the transit of 1882 Venus passes, still in a northwest direction, over the south part of the Sun's face, the transit occurring before she arrives at the ascending node. At ingress the east of Brazil, and at egress the West Pacific Ocean, are respectively in the middle of the hemisphere turned towards the Sun, so that ingress would be most retarded on the west coast of North America, and most accelerated at Kerguelen's Island, while for corresponding effects at egress Australia and the North Pacific would be the best positions.

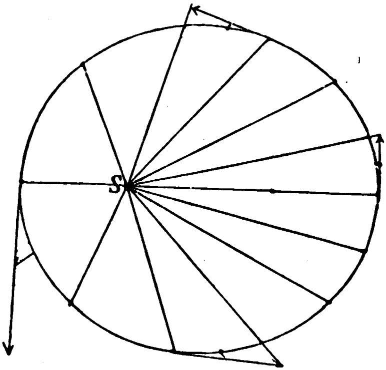
So far we have considered the effect of parallax on the ingress at two places, as distinct from the effect on the instant of egress, which is Delisle's method of treating the question; and this implies that we can compare the clocks at the two stations so as to know the difference of the two observed times. Now the only way of doing this for places not connected by telegraph is to set the clock to local time, and then to determine the difference between local and Greenwich time, or the longitude of the place, which may be done by the help of the Moon, as explained in Chapter III., and if a large number of observations be made the value of the longitude so found will probably be true to a single second. Now the quantity we have to measure is, under the most favourable circumstances, only 50 seconds of arc, a magnitude barely visible to the naked eye, and Venus takes 25 minutes of time to move over this space on the Sun's disc, so that an error of one or two seconds in setting the clock to Greenwich time at the different stations is not of so much consequence.

Another method has, however, been proposed for taking advantage of this slow motion of the planet without the necessity of setting the clocks to Greenwich time. Suppose we can find a station at which ingress will be accelerated and egress retarded, and therefore the duration of the whole transit lengthened, and another station at which exactly opposite effects will be produced and the duration shortened, then it is evident that it is sufficient to observe these two durations without comparing the clocks, and this is the method which Halley proposed. This difference of duration is the result of two causes: in the first place, an observer at a northern station will see Venus further south, and therefore nearer the Sun's centre, in the transit of 1874, which will lengthen the path across the Sun; and, in the second place, the rotation of the earth will carry the observer further to the east at egress, and will therefore apparently shift Venus to the west, and so hasten the egress. But this latter cause affects both northern and southern stations nearly alike in the transit of 1874, so that we have only to consider the difference of paths, which will be greatest for stations in Siberia and the Antarctic continent, the north and south parts of the hemisphere turned to the Sun. In the Transit of 1882 the longer path will correspond to the southern station; and further, as the South Pole is turned towards the Sun, if a station be taken near the south part of the earth's disc as seen from the Sun, the earth's rotation will carry the place westward (the Sun being below the Pole), and therefore still further lengthen the duration of transit as compared with a place on the west coast of North America, where the earth's rotation combines with the parallactic shift to shorten the duration. But unfortunately some of the places which give the greatest parallactic shift are practically inaccessible, and astronomers have to be content with the best available islands in the Southern Seas, the great Antarctic continent being virtually closed against them.

Before dismissing this subject we must allude to another valuable method, in which photographs of the Sun, with Venus as a black spot on his face, taken during transit, at northern and southern stations, will be made use of, the quantities to be compared being in this case the distances of the planet from the Sun's centre, as measured afterwards on the photographs. The way in which these measures may be made available will readily be seen by considering that a comparison of the times when Venus is at the same distance from the Sun's centre for two stations is exactly equivalent to a comparison of the times when the planet is at the distance of the Sun's semi-diameter, *i.e.*, on the Sun's limb at ingress or egress, the case which has been already considered. The same result may be obtained by measuring the distance between the centres during the transit; but though such measures may be made with great accuracy, the photographs have the advantage of giving a permanent record, which can be examined with the greatest care afterwards.

Though Transits of Venus offer the most favourable opportunity of determining the Sun's distance, they are such rare phenomena that astronomers have not been content with trusting to them alone, but have obtained very accurate results from another planet, Mars, which, in opposition, approaches us almost as closely as Venus herself; this is especially the case when the opposition of Mars takes place in that part of his oval where he is nearest to the Sun, which will bring him nearer to us by a fifth part of his average distance in opposition, whilst, if this take place in summer, when the earth is farthest from the Sun, the distance between the two bodies will be still smaller, being less than $\frac{2}{5}$ of the Sun's distance. The mode of observation is exactly the same as in the case of the Moon, though the quantity to be measured is a hundred times smaller, so that there must necessarily be considerable uncertainty; it appears, however, from the comparison of many observations made in the northern and southern hemispheres in the favourable opposition of 1862, that Encke's value of the Sun's parallax, deduced from observations of the Transit of Venus in 1769, was fully $\frac{3}{10}$ of a second of arc in error, and that the Sun's distance was in consequence over-estimated by about one-thirtieth part, making it about 92 millions of miles instead of 95 millions, an error which has been referred to a misunderstanding about the place of the Transit seen by some of the observers. This correction is supported by an indirect determination of the Sun's distance, from the velocity of light and the time it takes to reach us from the Sun, in consequence of which eclipses of Jupiter's moons (of which there are four) are found to take place, on the average, 8¼ minutes earlier than the predicted times, when we are nearest to him in opposition, and 8¼ minutes later when we are on the opposite side and Jupiter near conjunction, light having then to traverse the extra distance across the earth's orbit as compared with the length of its journey in the former case, from which it is inferred that light takes 16½ minutes to traverse the earth's orbit, which, with a velocity of about 186,000 miles a second, makes the distance of the Sun 92 millions of miles. Nearly the same result follows from the relation between the velocity of the earth in her orbit and the velocity of light. If the earth were at rest we should see all the heavenly bodies in their actual places, but as the earth is moving with about a ten thousandth part of the velocity of light, the light of a star will seem to come from a slightly different direction in consequence of our own motion. This effect was first observed by Bradley, and the true explanation of this apparent deviation in the position of a star (which he called aberration) was suggested to him by observing that when a boat was beating up against a head-wind, the vane pointed in slightly different directions according as the boat was moving in one direction or the other. Thus with a side wind the boat's motion would make the wind seem a little a-head, as by its passage through the air the boat would make a slight head-wind, which, combining with the real breeze, would make it seem to blow a little from the bow of the boat, whichever way that might be. Thus, suppose the wind blowing from the north, if the boat be sailing in an easterly direction the wind will, according to the vane, seem to come a little from the east, say N.N.E., while it will apparently shift to N.N.W. when the boat sails in a westerly direction. The same effect may be noticed from the motion of a carriage, or when running with a side-wind, the result being that the wind seems to come more from the direction in which we are moving. Just the same happens with the light of a star, which, like the wind, appears to come rather more in the direction in which the earth is moving. It is accordingly found that the *apparent* position of a star shifts with the direction of the earth's motion, the shift being greatest when the earth is moving sideways with respect to the star's direction, and nothing at all when directly to or from it. The faster the earth moves the greater will be this apparent shift, and the proportion of the earth's velocity to that of light will be given by the amount of shift. It may be remarked that the aberration of stars affords us a direct proof of the motion of the earth round the Sun, as such a shift cannot be accounted for on any other supposition. In the case of the planets there will be a double shift caused by the planets' and the earth's motions together, and instead of allowing for both of these separately, it is more convenient to find, from the known distance of the planet at the instant, the time which light takes to reach us from it, and to consider that the observation was made so much earlier, or, in other words, to antedate the observation by this interval. A little consideration will show that this amounts to the same thing as correcting for the shift; for the earth's motion will shift the planet apparently forward (*i.e.*, in the direction of this motion) by the space through which the earth has moved while the ray was coming, and thus the planet will be seen in the same direction as if it remained where it was when the ray left it and the earth was shifted back to its position at the same instant, since, as we have already explained, such a shift of the earth backward will apparently shift the planet forward through the same space. Tables being formed which give the places of the planets and the earth at any instant, it is thus easy to compare the observations made at any particular time with the places from the tables for an instant preceding this by the number of seconds which light takes to cover the distance between the planet and us, and thus the accuracy of the tables can be checked and corrections to them made when necessary.

On comparing the velocities of different planets with their distances from the Sun it will be seen that the former decrease as the distances increase, but not so rapidly; thus the velocity of Mars is half that of Mercury, but his distance is four times as great; the velocity of Saturn is one-third that of the earth, but his distance is about nine times as great; the velocity of Uranus is about one-fifth that of Venus, whilst his distance is nearly twenty-five times as great. Now these numbers (which are only approximate) suggest a connection between the velocity of a planet in its orbit and its distance from the Sun, of such a kind that the distance increases as the square of the velocity decreases; thus the square of the velocity of Mars is one-fourth that of Mercury, while the distance is four times, and where more exact calculations are made this rule is found to hold in all cases. This great law was discovered by Kepler, and was put by him in a slightly different form, viz.:—that the squares of the periodic times, or years, of the several planets increase as the cubes of their distances from the Sun; which follows from what has just been stated, since the period increases as the size of the circle increases and as the velocity decreases; so that the square of the periodic time increases as the square of the distance from the Sun increases, and as the square of the velocity decreases; but the square of the velocity decreases as the distance increases, whence finally the square of the periodic time increases as the cube of the distance. This is known as Kepler's *Third Law*, the other two, which were derived from laborious calculations founded on a large number of observations of the planet Mars in the first instance, and afterwards extended to the other planets, are: first, The planets describe ellipses* (or ovals), of which the Sun occupies one focus; second, the motion in these curves is more rapid in the part of the curve nearest the Sun, so that the fan-shaped sector which the line drawn from the Sun to the planet sweeps out in one day (or in one month) will be of the same area, though of a different shape, in all parts of the orbit, the angle being larger when the distance from the Sun is less. If the oval orbit be cut out of cardboard and cut through the points where the planet is at the beginning of each month, so as to form wedges



MOTION IN AN ELLIPSE.

The arcs marked off are each described in a month or twelfth part of the planet's year. The lines from the arrows to the curve show the space through which the Sun draws the planet, in a month and in half a month respectively. The ellipse is rather more oval than that of the Minor Planet Polyhymnia, and twice as oval as that of Mercury.

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[*] An ellipse is an oval curve, which may be traced by tying two ends of a piece of thread to two pins fixed on a drawing board, so that the thread is more or less slack, and running a pencil round in the slack of the thread. The two pins will be at the two foci, and according as the thread is more or less slack, *i.e.*, the pins proportionately nearer or further apart, the ellipse will be less or more oval.

having their points at the place of the Sun, all these wedges will be of exactly the same weight.

These three laws were established by Kepler as a result of observation; it remained for Newton to discover the principle from which these motions followed, in the law of Universal Gravitation, by virtue of which every particle in the universe pulls every other particle towards it with a force which decreases as the square of the distance between the particles increases. Newton proved by pure reasoning that such a force would be capable of making the planets move about the Sun in accordance with Kepler's Laws, if the Sun were supposed to consist of an enormous quantity of matter (in correspondence with his vast size) which would pull the planets, without their pull on him having much effect in moving his large mass. Similarly, the attraction between the earth and the Moon would be capable of making the Moon move in such an orbit as she actually describes. The next step was to show that the attraction of the earth, which makes an apple fall, is really the force which keeps the Moon in her actual orbit. Now an apple (or a stone) at the earth's surface falls sixteen feet in the first second through the earth's attraction, and at the distance of the Moon, which is sixty times as far from the earth's centre, it would fall $\frac{16}{3600}$ of a foot, or about $\frac{1}{20}$ inch in the first second if the force decreases as the square of the distance increases. Now the Moon really falls towards the earth by exactly this amount, though not in a direct line, for if left to herself at any instant she would go off in a straight line; but the earth gives her a pull which brings her into a curve, and the distance between her position in this curve and the straight line in which she would have gone off one second before, represents her fall towards the earth in the first second, which is found to be exactly $\frac{1}{20}$ inch. It may appear difficult to understand how the Moon can be continually falling towards the earth without ever reaching it, but it must be remembered that her motion, if left free at any instant, continually tends to carry her away, and that it requires a continual fall towards the earth to keep her in her course, this fall being, of course, in different directions at different parts of her orbit, since it is always directed towards the earth. This continual *fall* * towards the centre of motion is made sensible in a railway carriage running along a sharp curve; the passengers seem to be thrown outwards, because their tendency is to move in a straight line whilst the carriage is kept to the rails and being continually pulled towards the centre of the curve. In the same way if a stone tied to a string be whirled rapidly round, a strong pull on the hand holding it will be felt, and as soon as the string is let go the stone will fly off in the direction in which it was going at that instant. Although it is convenient to speak of the earth's attraction on the Moon, or the Sun's on the planets, yet really the earth does not pull the Moon more than the Moon pulls the earth, the law of gravitation being merely that there is a pull between them which tends to bring them closer together, but the earth, being more massive than the Moon, will not be moved so much. The case of a large and small stone tied together by a string and flung into the air will illustrate this; the pull on each, communicated through the string, is the same, but the small stone will circle round the large one, which pursues nearly the same course as if alone, being hardly disturbed by the pull through the string. With the earth and Moon the real state of the case is that every particle of the Moon pulls every particle of the earth, and every particle of the earth pulls every particle of the Moon with equal force, but there being more particles in the earth, the pull of the earth on any one particle of the Moon is stronger than the pull of the Moon on any one particle of the earth, though the pull of the earth on the Moon, as a whole (*i.e.*, on all its particles), is exactly equal to the pull of the Moon on the earth as a whole. In

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* This word is here used in an extended sense to express the result of a pull towards any centre, not merely to the earth's centre.

consequence of this mutual pull both the earth and Moon will move about a point in the line joining them, which is much nearer the earth than the Moon. This point is commonly called the centre of gravity of the two bodies, and is such that if we imagined them connected by an enormous rod, they would balance about this point, just as a large and small stone fixed at the two ends of a stick will balance about a point of the stick nearer the large stone. The motion of the earth and Moon will then be exactly the same as if they were connected by an elastic string, a certain point of which (the centre of gravity of the two bodies) is made to revolve round the Sun once a year, whilst both earth and Moon whirl round this point in ellipses once in a lunar month, the string stretching more or less, so that the distance between them alters. The motion of the Moon as seen from the earth will then be exactly the same as if she were moving in an ellipse about the earth at rest; but the earth's motion about the Sun will not be an exact ellipse, but an orbit, something like that of the Moon round the Sun, though the deviation from a true ellipse (caused by the pull of the Moon) is very much less.

One consequence of this pull on the earth remains to be noticed, viz., the tides. These are caused by the attraction of the Moon and Sun pulling the waters of the ocean, which are turned towards them (and therefore somewhat nearer) more than the solid mass of the earth (which is pulled just as if it were all collected at the centre), and thus the water on the part turned towards the Moon is heaped up, and similarly for the Sun's action. Again, the Moon (or Sun) pulls the earth more than the water on the other side, and therefore draws the earth away, causing high water also on this side. From this it would follow that there would be a lunar tide with high water when the Moon is on the meridian (both above and below the horizon), and also a solar tide with high water at noon and midnight. And this tide will be higher the nearer the Sun (or Moon) is to the Zenith or Nadir of the place, whence it follows that in summer the higher of the two solar tides is at noon, when the Sun is nearer to the Zenith than it is to the Nadir at midnight, whilst in winter the opposite is the case; and similarly for the Moon, according as she is north or south of the equator. In all this the earth's rotation has been neglected, the effect of this being to make the time of high water somewhat later, as the Moon has passed the meridian before its attraction has had time to produce its effect; and further, the reasoning only applies to the open ocean, there being no sensible tide in lakes and inland seas, where no great mass of water is acted on; even in the Mediterranean the rise of the tide is hardly perceptible. In channels and narrow seas the tidal wave comes from the ocean, and often takes many hours to traverse them; this will make high water so much later, giving rise to what is known as the Establishment of the Port, or the time that high water is after the meridian passage of the Moon and Sun, when they transit together at New and Full Moon. Since both Sun and Moon produce tides, they will, when pulling in the same or opposite directions, cause a much higher tide than when pulling at right angles, the high water caused by the Sun in the latter case partly filling up the low water due to the Moon, whilst at New or Full Moon the times of high water from both sources are the same, and they conspire to produce high tides, known as Spring Tides, those at first and last quarter being called Neap. The time of high water in the open ocean is in the latter case intermediate between the meridian passages of the Sun and Moon.

The height of spring tide at any place is found to be about $2\frac{1}{3}$ times that of neap at the same place; and as the solar tide is added to the lunar in the former case and subtracted from it in the latter, it follows that the effects of the Moon and Sun are as 5 to 2. Now the effect of the Moon in raising a tide (being the difference of her pull on the water and on the earth's centre) is the mass of the

Moon multiplied by the difference between $\frac{1}{60}$ squared and $\frac{1}{59}$ squared, which is very nearly twice the mass of the Moon divided by the cube of 60.* Similarly the effect of the Sun will be twice his mass divided by the cube of his distance (expressed in radii of the earth, as in the case of the Moon), which is 23,200, and this latter effect is $\frac{2}{5}$ of that of the Moon, so that his mass is about $\frac{2}{5}$ of 23,200 cubed divided by 60 cubed, or nearly $\frac{2}{5}$ of 400 cubed, *i.e.*, 25 million times that of the Moon. Now the Sun's diameter is 108 times that of the earth, whilst the earth's is not quite four times that of the Moon, so that the Sun's diameter is about 400 times that of the Moon, and his bulk 400 cubed (or 64 million) times the Moon's, the bulk of a globe being proportional to the cube of its diameter. From this it follows that, as the Sun's mass is $\frac{2}{5}$ of 400 cubed times the Moon's, his density is $\frac{2}{5}$ of hers, the densities being proportional to the quantities of matter in equal bulk. This is only a rough approximation to the truth; indeed the method is not susceptible of any great accuracy, and is only given as an instance of the way in which one heavenly body may be weighed, as it were, against another. In the case of the earth and the Sun, Kepler's Third Law enables us to find the proportion of the masses pretty accurately; for it is easy by this law to find the velocity with which a body would go round the Sun at the same distance as the Moon from the earth, though this is a purely ideal case, since the Sun's diameter is much greater than that of the Moon's orbit. The earth's distance from the Sun is nearly 400 times that of the Moon from the earth, whence the square of the velocity of this imaginary body going round the Sun would be 400 times the square of the earth's velocity in her orbit; and as 400 is the square of 20, we have the velocity of the fictitious body equal to 20 times the earth's velocity, or 364 miles a second; whilst the Moon's velocity under the

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* $\frac{1}{59^2} - \frac{1}{60^2} = \frac{119}{59^2 \times 60^2}$ which is very nearly $\frac{120}{60^2 \times 60^2} = \frac{2}{60^3}$.

influence of the earth's attraction is a little over $\frac{6}{10}$ of a mile in a second. Thus the Sun's attraction can retain a body in an orbit of the same size as the Moon's when moving with a velocity nearly 600 times as great as hers, so that as the earth pulls the Moon towards it through $\frac{1}{20}$ inch in one second, the Sun would pull a body at the same distance through this space in $\frac{1}{600}$ of a second. Now from the laws of falling bodies, a body pulled through $\frac{1}{20}$ inch in $\frac{1}{600}$ second would be pulled through 360,000 twentieths of an inch in one second;* so that the Sun's pull in one second is 360,000 times that of the earth on a body at the same distance, and therefore he must have 360,000 times the number of attracting particles that the earth has—in other words, his mass is nearly 360,000 times that of the earth; but his bulk is 108 cubed, or about 1,250,000 times that of the earth, so that his density is only a quarter that of the earth, or about $1\frac{1}{3}$ that of water, the density of the earth, as we shall presently see, being about $5\frac{1}{2}$ times that of water. The Moon's density is nearly $2\frac{1}{2}$ times that of the Sun, and therefore nearly $\frac{5}{8}$ that of the earth, and her mass about $\frac{1}{80}$ of the earth's mass. The above method may be applied to find the proportion of the mass of any planet which has a moon, to the Sun, all that is wanted being the distance of its moon and the length of the lunation; but in the case of other planets the problem is more difficult, though astronomers are able to make a fair approximation to the masses of such planets by the help of the attraction which they exert on their neighbours, pulling them a little out of the course which they would pursue if the Sun were the only attracting body, as he is by far the most important. The devia-

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* A heavy body on the earth falls through about 16 feet in the first second of its fall; $64 = 4 \times 16$ feet in two seconds from the start; $144 = 9 \times 16$ feet in three seconds; its speed increasing as the number of seconds from the start, and the space through which it is pulled by gravity as the square of the number of seconds. The same will apply to fractions of a second, the space through which a body falls in $\frac{1}{10}$ of a second being $\frac{1}{10}^2 \times 16 = \cdot 16$ foot, in $\frac{1}{600}$ of a second $\frac{16}{360000}$ foot.

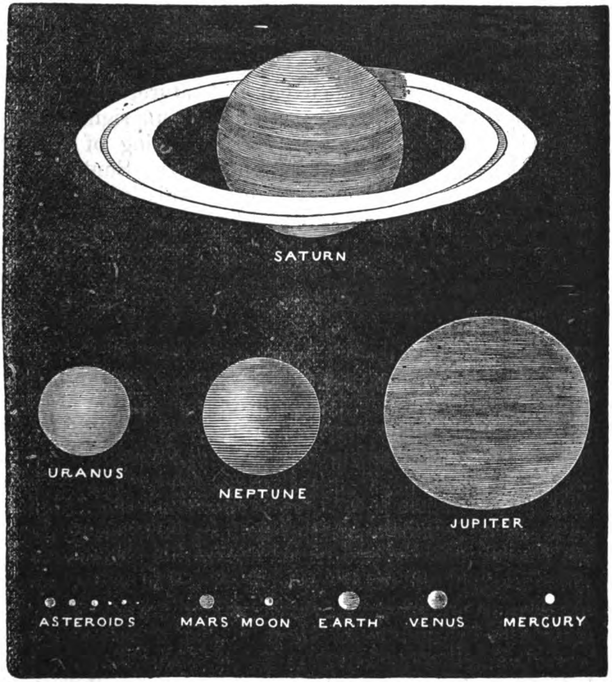
tions from exact ellipses round the Sun are, however, so small that it is only where great accuracy is aimed at that Kepler's Laws have to be slightly modified, the only exception being the Moon, which is greatly disturbed by the Sun's attraction, though the earth is still for her the preponderating influence.

It remains now to determine the mass of the earth as compared with our unit of mass, a pound (or a kilogramme). Three methods have been used for solving this problem. The first compares the attraction of a mountain with that of the earth by observing the deflection of a plumb line on opposite sides of the mountain, the angle between the zenith (which is the direction of the plumb line) and the pole being measured, and allowance made for the distance in miles that one station is north of the other. Now the mass of the mountain in pounds can be found from its size and average density, and its average distance from each station being known, as well as that of the earth's centre, the comparison of the attractions of the earth and mountain gives the mass of the earth in terms of that of the mountain, and therefore ultimately in pounds. In this way Maskelyne found that the attraction of the Scotch mountain Schehallien was about $\frac{1}{40,000}$th part of that of the earth, and the same method has been applied to other mountains. The second method is known as the Cavendish experiment. In this case the deflection of two balls connected by a light wooden rod, and suspended in a horizontal position by a long wire attached to the middle of the rod, was observed when two large leaden balls of known mass were brought near the suspended balls. The attraction of the earth on the latter could be inferred from the time in which they vibrated horizontally (by the twisting and untwisting of the wire), and the proportion of the earth's attraction to that of the leaden balls was thus obtained, and from this the mass of the earth. The principle of the third method, which was applied by Sir George Airy in the

Harton pit, is to find the difference between the attraction of the earth at the surface and at the bottom of a coal-pit, where the attraction of all the outer layer produces no effect. In this case the attractions were measured by observing the number of vibrations made in equal times by a pendulum at the surface and at the bottom of the pit, the force which makes the pendulum oscillate varying as the square of the number of vibrations in a given time. A pendulum at the bottom of the pit was found to gain 2¼ seconds a day more than at the surface, and the density of the earth was hence concluded to be about 6½ times that of water. The other methods gave smaller values, so that the average of all the determinations gives a density of about 5¼ times that of water, or twice that of surface strata. The bulk of the earth being known in cubic miles from its radius, there is no difficulty in calculating its mass in pounds; but the number is so enormous, that it conveys no idea to the mind, and is therefore not given here.

A curious progression has been observed to hold approximately in the distances of the planets from the Sun; and, though no reason has been given for any such law, it is a useful aid to the memory, and deserves mention from its having called attention to the gap between Mars and Jupiter, and thus led to the discovery of the minor planets. According to this so-called law of Bode (or Titius), the intervals between the orbit of Mercury and those of the other planets go on doubling as we proceed outwards, the distance from the Sun of the several planets, Mercury, Venus, the Earth, &c., being roughly as the numbers, 4, 7, 10, 16, 28, 52, &c., or, 4, $4+3$, $4+3\times2$, $4+3\times4$, $4+3\times8$, $4+3\times16$, &c.; but it must be remarked that the distance of Neptune, according to this law, should be 392 instead of 300, its real value.

Thus far the size and density of the planets have been considered, but when they are examined with a powerful telescope some further information may be gained, the chief point being the determination of the period of rotation, which is found, as in the case of the Sun, by watching the movement of any markings which may be seen on the disc. In this respect the planets, which all, as far as is known, turn from west to east, like the Sun and the earth, may be divided into two classes, the four inner, Mercury, Venus, the Earth, and Mars, rotating in about the same time, whilst the day for Jupiter and Saturn (and probably for Uranus and Neptune) is about ten hours. In the case of Mercury and Venus, evidence



COMPARATIVE SIZES OF THE PLANETS.

as to markings or spots is so conflicting that very little confidence can be placed in the values given for the length of their day. They are generally seen as brilliant spotless discs, gibbous or horned, like the Moon; Venus in particular being so dazzlingly white in a powerful telescope as to require the use of a coloured glass to moderate her light. Mercury is about three-eighths of the size* of the earth, whilst Venus is slightly larger than the earth, and of about the same density. Next to nothing is known of their physical nature, except that they show in their transits across the Sun signs of an extensive atmosphere, giving rise to a ring of light, which is seen round the edge outside the Sun's disc, and probably the cloudy state of this atmosphere prevents our ever seeing the real body of either.

The case is very different with Mars, which exhibits well-defined ruddy and blue-grey markings, which have been called respectively continents and seas, besides white spots at the poles of rotation, which are supposed to be snow or ice. These conclusions can only be accepted provisionally, but there is, at any rate, more justification for the terms than in the case of the Moon, Mars having probably an extensive atmosphere. He is rather more than half the size of the earth, and of somewhat less than $\frac{3}{4}$ of its density.

Of such minute bodies as the asteroids nothing is to be made out, but the next planet, Jupiter, is a magnificent spectacle, being more than ten times the size of the earth, though only $\frac{1}{4}$ of its density, and attended by four moons about the size of ours. These sometimes cross his disc, the shadow being also seen to traverse it, thus causing an eclipse of the Sun to the inhabitants of Jupiter; whilst at other times they are themselves eclipsed in the planet's shadow, or occulted behind his disc. These two latter phenomena are quite distinct, the former taking place when the satellite is hidden from the Sun, though to us, perhaps, apparently at some distance from the planet's disc, the latter when

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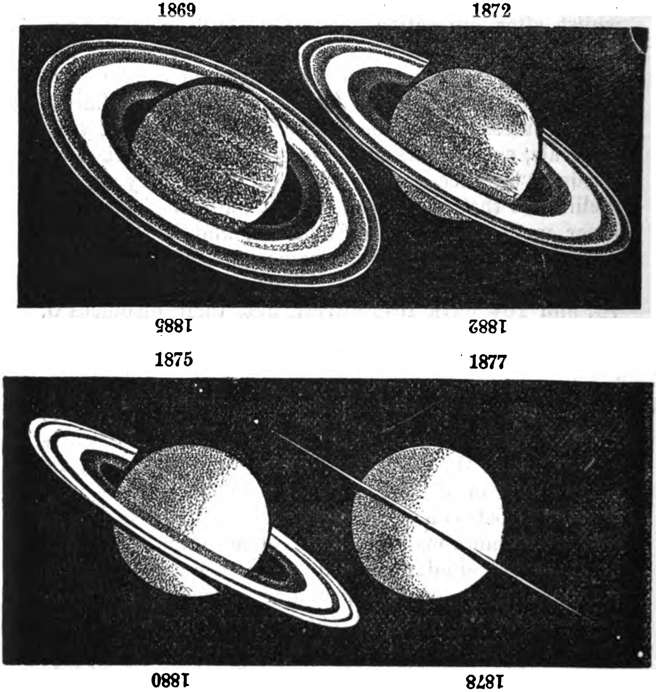
* This word is used as referring to diameter, not bulk.

the satellite is hidden from us. The times at which these two phenomena occur will be different unless the earth and Sun happen to be in a line with the planet, which will be the case in opposition. Before opposition, Jupiter being eastward of the prolongation of the line joining the earth and Sun, the eclipses will take place when the satellites are west of the planet, the earth looking round that side as it were, whilst after opposition the reverse will be the case. The motions of the satellites are eastward, and, like our Moon, they appear to turn on their axes once in each revolution round the planet, certain variations of brightness having been observed to recur at such intervals, as if a dark and a bright side were turned towards us in succession. Their orbits are very slightly inclined to that of Jupiter, so that eclipses of the three inner moons occur every lunation, and of the fourth very frequently, Jupiter's shadow being large as compared with their distances. Their periods are 1¾, 3½, 7⅙, and 16⅔ days respectively, and their distances 6, 9⅔, 15⅓, and 27 times the radius of the planet.

The disc of Jupiter is usually distinguished by several bright belts parallel (or nearly so) to his equator, which have been supposed to be clouds formed by the trade winds, which, from his rapid rotation, must be nearly due east, and the rapid changes in the form of the belts confirm this idea. Some of the belts are reddish, with dark belts between of greenish grey, and this variety of hue seems more marked in some years than in others.

Somewhat similar belts are seen on Saturn, but the striking feature of that planet is a wonderful ring, or rather system of rings, 70,000 miles in diameter, or one-third the size of the Moon's orbit, which we see more or less edgeways, they being inclined some 28° to Saturn's path. When we are nearly in a line with the crossing points (or nodes) of the ring with our plane, they are seen as a bright fine line crossing the planet parallel to the belts; this line disappears altogether when we see the rings exactly edgeways, so that the thickness must be very small, not more than a few hundred miles. These disappearances will occur at intervals of nearly fifteen years, half the Saturnian year, there being two parts of his orbit corresponding to our spring and autumn, for which the ring is placed edgeways with respect to the Sun, and therefore nearly so to the earth, which to an inhabitant of Saturn never



PHASES OF SATURN'S RINGS FROM 1869 TO 1877, AND FROM 1878 TO 1885. (*For the latter turn the figures upside down.*)

The figures are not intended to show the tilt with reference to the ecliptic, which can be inferred from the figure of the Seasons, p. 82.

seems to wander more than 6° on either side of the Sun. When the earth and Sun look at opposite sides of the ring (which is sometimes the case about the time of disappearance) it will only be seen as a black belt crossing the planet, and invisible outside the disc; in such cases there will be two disappearances close together, the first when the earth crosses from the bright side to the dark, and the second when it returns from the dark to the bright side of the ring. The phases presented by Saturn's ring are exactly analogous to the appearances of the earth's equator to a spectator on the Sun, which we have already described with reference to the seasons, remembering that the year for Saturn is nearly thirty of our years, and that we do not always see the rings *exactly* as they would be seen from the Sun.

Thus, starting from what would be spring for Saturn's northern hemisphere, when the ring is seen edgeways, the northern side will be presented more and more fully to us, till, after 7½ years, we get to Saturn's northern summer; the rings will after this appear to close up, disappearing at Saturn's autumnal equinox after 7½ years more, from which point the southern side is seen for 15 years, going through the same phases as the northern.

The system of rings consists of three bright and an interior dusky ring, which seems to be semi-transparent, allowing the body of the planet to be seen through it. How such a system can be preserved against the slightest disturbance from the attraction of other bodies has puzzled mathematicians, and after making various hypotheses they have been forced to the conclusion that the rings, if solid, liquid, or even gaseous, must inevitably end in being precipitated on to the planet unbroken, the only available alternative being that each ring, instead of being a coherent mass, consists of a large number of minute bodies revolving round Saturn like satellites, and forming an appendage somewhat similar to the Zodiacal Light round the Sun. Saturn is nearly ten times the size of the earth, but only on the whole one-ninth as dense, or two-thirds the density of water, but how much of his bulk is composed of atmosphere we have little means of judging, and can therefore say nothing of the density of the true body of the planet (if he have any), though we know that his mass is 100 times that of the earth, his bulk, including his atmosphere, being nearly 1,000 times the earth's. A similar remark applies to Jupiter, which has also, in all probability, a very extensive atmosphere. Saturn is attended by eight moons, revolving in periods ranging from 1 to 80 days, and at distances of from 3⅓ to 64 times the radius of the planet, or from a half to ten times the distance of our Moon.

Uranus and Neptune are so far off that very little can be made out about them, except that they have nearly circular discs of 4″ and 3″ apparent diameter respectively, corresponding to a real diameter of 4½ and 5½ times that of the earth, whilst the density of Uranus is a fifth, and that of Neptune, a seventh of the earth's, or not far from the density of water. Four satellites to Uranus and one to Neptune have been discovered up to the present time, but there are only two or three telescopes in the world capable of showing them, so faint is their light. In the case of Uranus, the moons move in paths very much inclined to that of the planet round the Sun, and in a retrograde or westward direction.

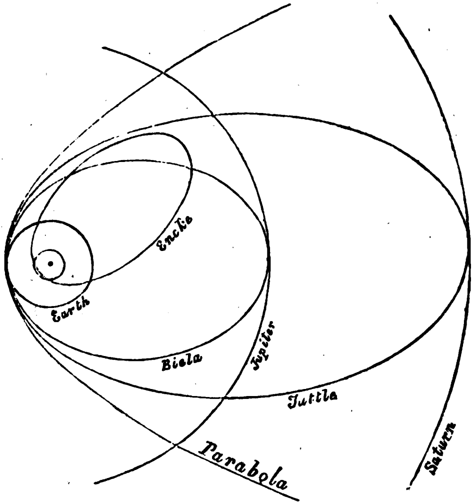
The conditions to which the several planets are exposed are so various that it is difficult to form any conception of their state; to Mercury the Sun appears seven times as large in area as to the earth, whilst to Neptune he appears of only $\frac{1}{900}$th the area, and the amount of light and heat received by these bodies will be proportional to the apparent area of the Sun's disc, and therefore to these numbers. What proportion of this heat is reflected away into space by the atmospheres of the several planets is not exactly known, nor the effect that clouds may have in preventing the radiation of heat which takes place with a clear sky, but it is difficult to see how causes of this kind could operate to such an extent as to raise the surfaces of the outer planets, Uranus and Neptune, much above the temperature of space, which is known to be nearly three times as far below the freezing point as that is below the boiling point of water, though internal heat may in these bodies be far greater than that of the earth, and thus keep up a comparatively high temperature without much help from the Sun.

Further, the force which makes bodies fall must be very different for the several planets. On the Sun it would be twenty-seven times that on the earth, on Jupiter two-and-a-half times, on Saturn and Venus about equal to gravity on the earth, on Mars and Mercury one-half, and on the Moon only one-sixth, whilst on the asteroids it would perhaps range from $\frac{1}{40}$ to $\frac{1}{500}$. The weight of the same body being so different at the surfaces of different planets, volcanic and other forces of expansion would produce very different effects; and the same remark applies to muscular force. A man who can jump 5 feet high on the earth would be able to jump 30 feet on the Moon, and some 2,500 feet on the smallest asteroid, whilst on Jupiter he could only jump 2 feet, and on the Sun only about 2 inches; and the muscular effort required to raise a mass of 100 pounds on the earth would raise 600 pounds on the Moon, but only 4 pounds on the Sun. Further, the rapidity of rotation, which tends to throw bodies off at the equator, varies greatly for the different planets, being very large in the case of Jupiter and Saturn, which causes a bulging out of their equator to the extent of $\frac{1}{15}$ and $\frac{1}{10}$ of their diameters respectively, that of the earth being only $\frac{1}{300}$, and of Mars $\frac{1}{60}$.

CHAPTER V.

The bodies which we have next to consider, though belonging, at least temporarily, to the solar system, present peculiarities which separate them completely from all the planets, whether large or small. Whilst the planets are massive globes with definite boundaries, comets are diffused bodies with no distinct outline, and generally of enormous volume, but of such small mass that no appreciable disturbance is caused in a planet's motion even by the near approach of one of these strange bodies. But it is not only in their constitution that comets differ from planets; they are equally remarkable for the irregularity of their motions. Thus in a single day the comet of 1472 moved in the heavens through 40° (a ninth of a complete circle), and that of 1861 through 12°, the apparent motion afterwards slackening till it became hardly sensible, and other comets have moved nearly as rapidly for a time. A considerable part of this large apparent motion arises from our own motion in the opposite direction to that of the comet, which in the cases referred to was very near the earth at the time, and this parallactic effect must, as in the case of the planets, be allowed for before we can find the true path of the comet about the Sun.

We saw that all the planets moved in one direction in nearly circular orbits very slightly inclined to the earth's path (except in the case of some of the minor planets), but comets are found in all parts of the heavens, and moving in all directions, the ellipses which they describe being commonly much inclined to the earth's path, and so much elongated that in most cases they cannot be distinguished in the portion near the Sun (which is the only part where we can follow them) from another curve called a *parabola*, which is something like the half of a long ellipse, the distinction being that in the parabola the two branches separate further and further, and never come round, as is the case with the ellipse. The motion in these parabolas is, however, strictly regulated by Kepler's Second Law, that the sectors (or wedges) formed by lines drawn to the Sun from the comet every day are equal in area, so that the motion in the part near the Sun is exceedingly rapid, to make up for the shortness in the radii of the sector. Thus Newton's comet of 1680, which passed within a third of the Sun's radius from his surface, had a velocity of 250 miles a second when nearest to him, whilst that of 1843, which passed even closer, almost touching the surface, had the still greater velocity of 370 miles a second, taking only two hours to go half round the Sun. On the other hand, the comet of Faye, which revolves round the Sun in 7 years and 5 months, resembles the planets most in its motions and in its orbit, though its least distance from the Sun is only $\frac{3}{10}$ of its greatest, whilst for Mercury it is $\frac{2}{3}$, and for



ORBITS OF COMETS.

Biela's and Tuttle's comets are taken as types of the Jupiter and Saturn class of comets respectively, and the orbits are made slightly less oval than the actual paths, to show how an ellipse may touch the Earth's path on the outside and Jupiter's or Saturn's path on the inside.

one of the small planets, Polyhymnia, it is ½, this being the most oval orbit among the planets. With regard to the inclinations of their orbits, comets seem rather to avoid the ecliptic, only ¼ of the whole number having inclinations lying between 0° and 30°, whilst about ⅜ lie between 30° and 60°, and an equal proportion between 60° and 90°; and further, the motion in these orbits is about as often retrograde as direct, though the great majority of the periodic comets circulate in the same direction as the planets, while of those which move in parabolas (or exceedingly long ellipses) two-thirds have a retrograde or westward motion. The orbits of the periodic comets are also generally not much inclined to the paths of the earth and other planets.

Comets are as various in their aspects as in their movements, but there is a family likeness binding them all together, and indicating that they are all subject to somewhat similar conditions. A large proportion are exceedingly faint objects, only to be seen in large telescopes as small spots of hazy light, very few being visible to the naked eye, though four or five new comets are on the average picked up every year. In old times comets generally burst unexpectedly on the view, but this is hardly ever the case now, as astronomers are continually on the watch to detect any comet as soon as it can be seen in a powerful telescope, so that by the time it has become at all conspicuous its path is well determined, and the brightness it will attain is tolerably well ascertained. Since the invention of the telescope, astronomers have been able to watch the growth of large comets from their first appearance, as spots of nebulous light, and have thus formed some idea of the development of the different parts of which a comet consists, viz., the nucleus, the coma or head, and the tail. Taking the case of a large comet before its approach to the Sun, nothing will probably be seen but the head—a mass of hazy light, with a bright point in the centre called the nucleus, which is often absent in the small comets. As the comet comes more under the Sun's influence near perihelion, the nucleus commonly throws out jets of light towards the Sun, which curve back and apparently give rise to the tail—a band of light sometimes extending many degrees from the head (120°—or a third as much again as the distance from the horizon to the zenith—for the comet of 1861), and having a real length in some cases exceeding the distance of the earth from the Sun. Ordinarily the tail does not attain its full development till after the approach to the Sun, and the same is true of the jets emitted from the nucleus; but the apparent length of tail is greatly affected by foreshortening. Its general form somewhat resembles a parabola, with the nucleus as focus, and having a dark division running along its axis; but in many comets it is considerably curved backwards like a plume, and there are frequently secondary tails darted out in other directions in the form of a fan, besides occasionally a sort of spurious tail directed to the Sun. Of the causes which produce these tails nothing is certainly known, though there seems very little doubt that they are due to a repulsive force of some kind from the Sun, modified by the action of the nucleus; but on what this force is exercised seems an open question, as it is almost incredible that matter could be projected with such an enormous velocity—a tail 60 millions of miles long (two-thirds the interval between the earth and the Sun) having been formed in two days in the case of the comet of 1680, and a still longer tail in a single day in the comet of 1843. But until further observations have been accumulated, it appears hopeless to attempt an explanation based on an imperfect knowledge of the facts.

Of late years the spectroscope has been applied to several faint comets, the result being that the spectra of their heads were found to consist of three bright bands, characteristic of carbon in some form. The bright comet of 1874 afforded an opportunity which had not presented itself since the invention of the spectroscope, but very little more was made out in this case, for most of the light of the nucleus and bright jets in the head was spread out into a continuous spectrum (indicating probably that it is reflected sunlight) which almost overpowered the bright bands. The light of the tail appeared also to be chiefly reflected sunlight, as in the case of the zodiacal light, and there our knowledge of this comet appears to end.

A connection has however in recent years been established between some other comets and certain groups of small particles called meteorites, which in their journey round the Sun sometimes pass through the earth's atmosphere with such an enormous velocity (35 miles a second on the average) that they are ignited by the friction of the air, and show themselves to us as "falling stars," at a height of about 73 miles on the average. Ordinarily these falling stars are completely consumed in their passage through the air by the time they have got within about 52 miles of the earth's surface, being generally extremely minute bodies, probably only a few grains in weight; but in some few cases considerable masses have fallen to the earth after the explosion of a large meteor. Such masses are composed largely of an ore of iron, and appear to be of different character from the ordinary falling stars, which generally appear in streams, all the particles in any one stream moving in the same direction, as is shown by the fact that their paths all radiate from the same point of the heavens, which is the "vanishing point" of a system of parallel straight lines seen in perspective. Thus about April 20 a large number of meteors are seen diverging from a point about midway between the bright star Vega and *α* Ophiuchi; another stream, known as the Perseids, on account of their diverging from the constellation Perseus, is encountered by the earth about August 10; another well-marked shower, radiating from *γ* Leonis, and hence called Leonids, is met with near November 14; and again, on November 27, comes another group diverging from the region lying between *γ* Andromedæ and Cassiopeia. These are only the principal streams, a list of more than a hundred well ascertained groups having been formed, in each of which all the members are travelling nearly in the same direction.

Now all this clearly points to an external origin for these bodies; and as the supposition that they are cinders thrown out from the lunar volcanoes affords no explanation of their regular recurrence, besides being in itself improbable, we are thrown back on the theory that they are really minute members of the solar system circulating round the Sun in streams. This view is supported by two facts which have been noted in connection with the Leonids: 1. That remarkable displays of these meteors occur every 33 years, the last having been observed in 1866; and 2. That the time when we pass through the thick of the shower gets later and later by about a day every 33 years.* The first circumstance might be explained by supposing this group of meteors to revolve round the Sun nearly in a circle, in a little more than a year or a little less, so that every 33 years the earth caught it up, or it caught the earth up, the meeting point of the paths of the meteors and of the earth (which are somewhat inclined to each other since the meteors do not come in the direction of a point in the ecliptic) being at the place where the earth is on Nov. 14; or else by supposing the meteoric stream to circulate round the Sun in a long ellipse in 33 years. The shift of the meeting point of the paths of the earth and meteors by 29′ corresponding to half a day in 33 years, enables us to decide in favour of the last supposition, as it is found by elaborate calculations that the attractions of the planets would cause exactly such a shift of the line of nodes in the case of a long ellipse. Now the period being 33 years, the mean distance, or half the

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* Half of this lagging is due to a shift of the equinox itself along the ecliptic, as will be explained in the next chapter, the actual shift of the meeting point of the meteors with the earth's orbit referred to the stars being only half a day every 33 years.

long axis of the ellipse, is found by Kepler's Third Law to be nearly that of Saturn, or about 10 times that of the earth; but as these meteors move in a very long ellipse, they will, when farthest from the Sun, be about as distant as Uranus. The direction in which they are moving at the time the earth meets them being known, their velocity can be calculated from Kepler's Second Law, and their path found. When this was done the orbit was found very closely to resemble that of the first comet of 1866, and a similar investigation in the case of the Perseids showed that they moved in the same path as the great comet of 1862, whilst the April star-shower appeared to follow the course of the first comet of 1861; but the connection between meteors and comets was most clearly established in the case of the stream of November 27 and Biela's double comet, for not only was there an unusual display of meteors just about the time the comet was expected to be near us, but a comet was actually seen just afterwards in the southern constellation Centaurus, very near the part of the heavens *towards* which the meteor stream was moving, though, unfortunately, cloudy weather at Madras (where a telegram predicting the probable appearance of the comet in the track of the meteors was sent) only allowed the comet to be seen on two days, leaving it still an open question whether the two heads of Biela's comet were observed on the two days respectively or not. But however this may be, it seems almost certain that on the night of November 27 we passed through the outer part of a comet, the particles of which appeared as a shower of falling stars. There is one noticeable feature about some of the meteor streams, especially that of Nov. 14, viz.:—the large arc of their ellipse over which they are spread. Thus the dense part of the stream of the November meteors takes more than a year to pass the meeting place with the earth's orbit, the shower of 1867 having been nearly as remarkable as that of 1866; but though the foremost particles will have moved through a large arc by the time the last are clear of the earth, this is in the part of the ellipse near the Sun, whilst when the stream gets to the distant part, the arc passed over in a year will be so small that all the particles will be tolerably near together, and they may then form part of a moderately compact comet. This branch of astronomy is, however, of such recent growth that much is still uncertain.

We will now give a brief account of a few of the most remarkable comets which have appeared in modern times, the records of the ancients being too vague to be worth mention here. The great comet of 1680 has been already alluded to, as being remarkable for its near approach to the Sun's surface, and also for the amazing rapidity with which its tail was formed, extending over fully 70° in the heavens. But this comet is chiefly memorable from its having led Newton to the conclusion that these bodies move in parabolas, or in very long ellipses, a result which he had previously shown would follow from the Sun's attraction if the velocity were greater than that corresponding to the same distance from the Sun in an elliptic orbit. The way in which the velocity at the same distance from the Sun varies with the nature of the orbit may be readily understood by considering the simple case of motion in a circle, and supposing the velocity increased or diminished. If the body have a greater velocity, and therefore move over a certain space in less time, the Sun will not have pulled it quite so far towards him, so that it will have run off the circle as it were, describing a curve of larger radius, and thus we get either a long ellipse, a parabola, or even an hyperbola, all of which lie outside the circle, just touching it at the point where they approach most nearly to the Sun. If the velocity be about $1\frac{2}{5}$ that in the circle a parabola will be described, if less than this an ellipse, and if greater an hyperbola. On the other hand, if the body take longer to move over a certain space, or have less velocity than in the circle, the Sun will have pulled it further towards him, and it will therefore describe an ellipse, which falls altogether inside the circle, touching it only at the point where it is furthest from the Sun (see fig. page 76). Thus the November meteors and the comet of 1866 have, when nearest the Sun, a velocity greater than that of the earth, whose nearly circular path they just touch, and, when furthest, a velocity less than that of Uranus, whose orbit they also nearly touch, but internally.

The comet of 1744 deserves mention from its having exhibited six tails spread out in a fan shape, in which respect it resembled the great comet of 1861, on June 30. It was a remarkably brilliant object, being as bright as Jupiter shortly before its perihelion passage. In 1769 appeared a bright comet, with a tail 100° in apparent length, corresponding to a real length of 40 millions of miles (half the interval between the earth and Sun). The comet of 1811 was visible for seventeen months, and was accompanied by a tail more than 100 millions of miles long, though its apparent length never exceeded 25°. From the length of time during which it was observed, the deviation from a parabola was quite sensible, though the period of revolution appears to be no less than three thousand years, the ellipse being so elongated that the greatest and least distances of the comet from the Sun are respectively 420 times and about equal to that of the earth; so that the comet is carried to a distance fourteen times that of Neptune; but this, after all, is only about 1-500th part of the distance of the nearest fixed star. With regard to the comets previously mentioned, the observations are insufficient to enable us to distinguish with certainty between their orbits and parabolas, all that is certain being that their ellipses must be exceedingly elongated. In 1819 a fine comet appeared, which passed over the Sun's disc, being seen as a dark nebulous spot.

The comet of 1843 first showed itself in the northern hemisphere by its tail, the head being below the horizon. In southern latitudes it was a most brilliant object, being actually seen at noon close to the Sun on two successive days, with a tail several degrees in length, and afterwards, when it got clear of his rays, in the evening twilight, a tail 65° in apparent length was visible, the real length being some 200 millions of miles, or more than the diameter of the earth's orbit. The orbit of this comet is the most remarkable known, passing within about 100,000 miles of the Sun's surface, but whether it is a parabola or an ellipse of moderate or even of short period cannot be determined, as the path during the period of observation was so little curved that it could hardly be distinguished from a straight line. This arose from our being able to observe only that portion of the orbit which was about 200 times as distant from the Sun as the perihelion was.

The next large comet was that of 1858 (Donati's), which was a most beautiful object in the autumn of that year, with a tail like a plume, some 60° long, corresponding to a real length of more than 50 millions of miles. The head in its apparent course passed nearly centrally over the bright star Arcturus, but nothing peculiar was noticed. The most remarkable feature in this comet was the system of parabolic arches which formed the head and tail, arranged symmetrically with the nucleus at the focus. Its path appeared to be an ellipse of about 2,000 years' period, making the greatest and least distances from the Sun, respectively about 300 times and $\frac{3}{5}$ths that of the earth.

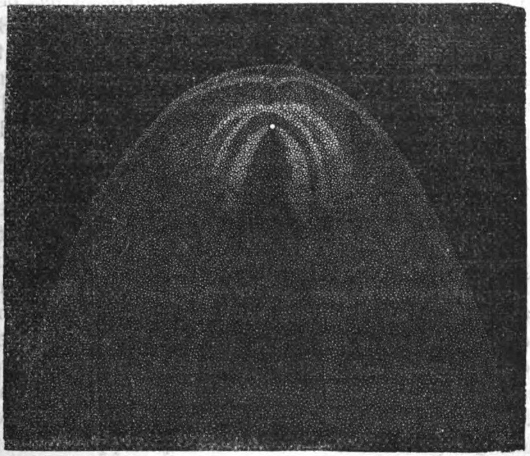
The comet of 1861 surprised astronomers in these latitudes by its sudden appearance above the horizon, though it had been watched for some time in the southern hemisphere. On June 30, when it was first seen in this country, we were probably actually passing through the tail, which was then seen as a great fan, the only unusual appearance noticed being a phosphorescence in the northern sky, something like an aurora. At this time the head of the comet was some 14 millions of miles off (nearly 60 times the Moon's distance). On July 2 the tail extended over 120°, reaching far past the zenith, but its real length was only 40 millions of miles, and as the comet receded from the earth the apparent length rapidly diminished. For a few days this comet was a splendid spectacle, and the fans of light seen in the head were very fine. Its period appears to be about 400 years, the greatest and least distances being respectively 110 times and $\frac{4}{5}$ that of the earth from the Sun.

In August, 1862, a fine comet appeared, the head when brightest being nearly equal to a star of the first magnitude, with a tail some 25° long, accompanied by two secondary tails. From one side of the nucleus very remarkable jets of light were emitted, afterwards curving round towards the tail, which appears to have been, contrary to the general rule, considerably inclined to the direction opposite to the Sun, and there was a lopsided character about this comet which presented a marked contrast to the symmetry of Donati's comet. The orbit of this comet (which is similar to that of the August meteors) is an ellipse with a period of 120 years, the greatest distance from the Sun being about 50 times that of the earth ($1\frac{2}{3}$ times that of Neptune), and the least distance nearly equal to that of the earth.

Coggia's comet of 1874 was similar to the last named comet in general appearance, and in position in the heavens. The head was remarkable for intersecting parabolic arches of light, which gave it a very beautiful appearance in a large telescope.

Among the periodical comets, Halley's is the most famous both for its size and for the regularity of its apparitions at intervals of about seventy-six years; twenty-two having been recorded between B.C. 12 and A.D. 1835. This was the first comet of which the return was predicted, Halley having found the orbits of the comets of 1531, 1607, and 1682 to be very similar, from which he concluded that they were really three apparitions of the same comet, which might be expected to return about the beginning of 1759, the period from 1607 to 1682 being shorter than the average through the attraction of Jupiter. At its last appearance in 1835 the comet was by no means so striking an object as on former occasions, when it filled Europe with alarm; but though it appears to have lost much of its glory, it will doubtless be a conspicuous comet at its next return in 1910. This comet approaches the Sun within $\frac{3}{5}$ths of the earth's distance from him, and recedes to a distance exceeding by one-sixth that of the planet Neptune.

Another very regular periodic comet is that known as Encke's, of which twenty-one returns, corresponding to twenty-eight revolutions, have been observed since 1786, the period being not quite $3\frac{1}{3}$ years. This is a small comet, barely visible to the naked eye even under favourable circumstances, and usually destitute of a tail; but much interest attaches to it from the fact that its period has diminished by about two days since its first appearance, which has been supposed to afford evidence of the existence of a very rare resisting medium in space which, by diminishing the comet's velocity, would make it describe a smaller orbit with a greater *angular* velocity. Its distance from the sun ranges from that of Mercury to four-fifths that of Jupiter. Biela's comet, with a



COGGIA'S COMET.

period of 6¾ years, is remarkable from the circumstance of its orbit intersecting that of the earth, a collision having probably occurred in 1872, November 27, as already mentioned. A still more remarkable fact about it is that in 1846 it divided into two distinct comets, which separated to a distance of about three-quarters that of the Moon from us; an interval which, at the next apparition in 1852, had increased to about six times the Moon's distance, with a difference in the periods of the two heads of fifteen days. Neither comet has been certainly seen since, though they were due in 1859 and again in 1866, and if either of them caused the meteor shower of 1872, November 27, they must have been retarded six months in the interval since the last appearance in 1852. Biela's comet was first observed in 1772, but has only been seen at six of its returns since that time. Its greatest and least distances from the Sun somewhat exceed those of Jupiter and Venus respectively.

The other periodical comets are given in the list at the end of this work, with a few particulars about their orbits. It will be noticed that the greater number of these reach a little beyond that of Jupiter, and, further, the plane of the orbit is so adjusted with reference to the direction of its length that each comet passes very near Jupiter, who may therefore, by his attraction, possibly have converted its parabolic orbit into an ellipse of short period. This is what actually happened in the case of Lexell's comet, which was found in 1770 to be moving in an ellipse of 5½ years' period, through its having passed very close to Jupiter in 1767, and before it was again seen the orbit was again completely deranged by another and still closer approach to the same planet, which appears to have greatly increased the least distance from the Sun, carrying the comet altogether beyond the range of our vision, even when nearest. This comet approached the earth in 1770, within six times the distance of the Moon, without causing the slightest alteration of our course, though the comet's path was much disturbed.

CHAPTER VI.

To the naked eye on a fine night the stars bewilder us by their number, making it impossible to give each of them a separate name, on which account the practice was adopted of grouping them into constellations, named from some fanciful resemblance to or connection with men or animals. In early times the stars were distinguished by their position in the constellation to which they belonged, but afterwards, as the less conspicuous stars began to be observed, those in each constellation were distinguished by the successive letters of the Greek alphabet in the order of their brightness, so that *α* Aurigæ would be the brightest star in the constellation Auriga, *β* Aurigæ the next brightest, and so on, numbers being used when the alphabet was exhausted. For the stars which have been observed only in modern times it has, however, been found more convenient to give the name of some catalogue in which the star's place is given, and the number corresponding to the star in that catalogue, and thus every star that has ever been observed is distinguished. When it is stated that there are catalogues which contain 100,000 stars, the necessity for careful nomenclature, for the smaller stars at any rate, will be at once apparent. With the naked eye some 3,500 stars are to be seen in England, and of these only about 2,000 at any one time; the number thus visible in the whole heavens, including the southern portion, always below our horizon, is about 15,000; but when the telescope is applied the multitude of stars is enormously increased with every increase in the size of telescope, and very soon gets quite beyond our powers of counting even. Every gradation of brightness is found in the heavens (except in the case of the very brightest stars), but for convenience the stars visible to the naked eye are roughly classed in six orders of brightness, or magnitudes as they are called, certain very bright stars, fifteen or twenty in number, being called first magnitude (though by no means exactly equal in brightness); after these come about 60 stars of the second magnitude, about 120 of the third, and so on; but though these classes do very well to give an idea of a star's brightness, greater accuracy is in many cases required, and thus half magnitudes are introduced, a star of the 3½ magnitude being intermediate in brightness between the third and fourth magnitudes, in delicate observations of changes in the brightness of certain stars, tenths, or even hundredths of a magnitude are used to express the relative brightness of the star as compared with those of the standard magnitudes, so that instead of speaking of a star roughly as of 3½ magnitude, we might call it 3·6, or perhaps more accurately 3·62. Below the sixth magnitude we have magnitudes only visible in the telescope, stars of any one magnitude being 2½ times as bright as those of the magnitude below, that is, two stars of the eighth magnitude very close together would not be quite so bright as a single star of the seventh magnitude, whilst three would be brighter. With the first six magnitudes this relation does not hold exactly, the classification being somewhat arbitrary; indeed different observers have varied considerably in their scale, though agreeing pretty well in the two extremes, and making 100 sixth magnitude stars equal in brightness to an average first magnitude, a relation which agrees exactly with the scale of 2½ for each magnitude.

We shall now endeavour, with the help of the Key Map (Frontispiece),* to enable the reader to recognise

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* This map represents part of the imaginary sphere of the heavens as it would be seen on a moonlight night (when the brighter stars only are visible), from a point at a distance of half the radius beyond the south pole of the sphere, stars below the fourth magnitude being omitted. The southern constellations, such as Scorpio, Sagittarius, &c., are necessarily much distorted, it being impossible to represent properly a spherical surface on a sheet of paper. The principal stars are distinguished by letters of the Greek alphabet, and the constellation to which any star belongs will be found on that side on which the letter is placed. The bottom, left hand, top, and right hand, correspond respectively to the southern part of the heavens at 10 P.M. in spring, summer, autumn, and winter, the opposite side being in each case below the northern horizon, which passes at a distance of 51½° from the Pole for London.

the most conspicuous stars, in which he will be much assisted by the grouping into constellations, conventional though it is. In the first chapter mention was made of the Pole Star; but this star is not very conspicuous, and we did not point out how to find it readily. On any fine night if we turn to the north (so as to have our back to the Sun at noonday) we shall see seven bright stars forming the constellation of Ursa Major (the Great Bear)—which will be found below the centre of the Map and a little to the left—the two right hand stars of which point pretty nearly to the Pole Star (at about six times the distance between them), and are therefore called the Pointers. In winter in the evening these stars are below the Pole and low down in the north, but in summer they are above the Pole and nearly overhead. As already explained the stars preserve the same positions among themselves, swinging as a whole round the Pole, and thus the seven stars of the Great Bear will be readily recognised by the form of the constellation, however it be turned with respect to us. The Pole Star, found in this way, will be seen to form part of a somewhat similar though smaller constellation of seven stars, hence called Ursa Minor, or the Little Bear, which never alters its height much, swinging round the tip of its tail (the Pole Star). A line carried from the Great Bear's tail through the Pole Star, and as far again beyond, will strike a conspicuous group of five principal stars, arranged something like the letter W, which is known as the constellation Cassiopea, and forms a convenient landmark in the heavens. It will be understood that in this and other constellations only the principal stars are alluded to, though there are a large number of smaller stars visible to the naked eye, whilst the telescope reveals almost countless multitudes. Carrying a line from the Pole through the most westerly of the stars in Cassiopea, and as far beyond, we come upon a large square formed by four bright stars, three of which are in the constellation Pegasus, whilst the fourth, or north-east star of the square, is *a* Andromedæ. Each side of this squar is about 15° in length, or nearly three times the distance between the Pointers, which are a little over 5° apart. The other two conspicuous stars in Andromeda, β and γ, form a sort of tail to the north-east of the square, and still further eastward is the consellation Perseus. A line through the two westernmost stars of Cassiopea, β and α, will strike γ Andromedæ, and about as far beyond will pass a little west of the Pleiades, a cluster of stars of which seven are ordinarily visible to the naked eye (though several more may be seen on a very fine night), whilst nearly 15° further is a V-shaped cluster, called the Hyades, having a first magnitude star, Aldebaran, at one tip. Both these clusters belong to Taurus, the Bull, which is one of the constellations of the Zodiac, or belt of the heavens, extending 8° on either side of the ecliptic, and including the paths of all the principal planets, which are never far from the ecliptic. The Zodiac is divided into twelve constellations, each occupying about 30°—Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces—the order given being that in which the Sun passes through them, or from west to east. Aries has two bright stars, α and β, 4° apart, and nearly midway between the Pleiades and Pegasus; in Gemini are two first magnitude stars, Castor and Pollux, north of the ecliptic, about 50° nearly due east of the Pleiades; Cancer is not a conspicuous constellation, but Leo will be recognised at once by six stars in the shape of a sickle, the first magnitude star Regulus forming the handle, 40° south-east of Castor and Pollux. Virgo contains one first magnitude star, Spica (the ear of corn), 10° south of the equator and more than 50° from Regulus. The remaining constellations in the Zodiac are not conspicuous, though Scorpio has several bright stars, including one of the first magnitude, Antares, but this constellation is too low in these latitudes to be well seen. It will be remarked that several of the brightest stars referred to above have names of their own independent of the constellation they are in. This is a relic of the old practice of naming, or rather describing, the individual stars, the words being generally corruptions of the names given by the Arabian astronomers to define the position of a particular star in the constellation, and these are still retained, though the star is also known by its proper Greek letter, coupled with the name of the constellation; thus Antares is also called α Scorpii, Aldebaran, α Tauri, and so in other cases.

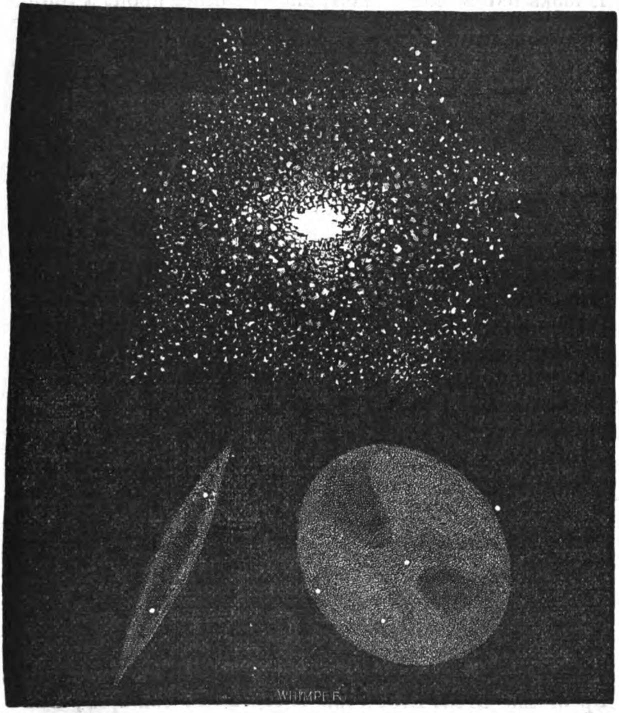
Among the constellations north of the Zodiac, Boötes is distinguished by the brightest star of the northern hemisphere, Arcturus, which is nearly pointed to by the last two stars of the Great Bear's tail; 20° north-east of Arcturus is the constellation of the Northern Crown (Corona), composed of a tolerably perfect wreath of stars. A line from the tip of the Great Bear's tail through the Crown, and carried as far beyond, will strike two stars 5° apart, α Herculis of the third magnitude, and α Ophiuchi of the second, the other stars of the constellation Hercules lying to the north of these two, and therefore east of Corona, whilst those of Ophiuchus lie to the south. Still further east of the Crown is the very bright first magnitude star, Vega or α Lyræ, which with a small star near forms a sort of pendent to a lozenge of four stars, and is to be seen not far south of the zenith in the autumn evenings. In the direction of the lozenge (*i.e.*, south-east) lie three bright stars, some 3° apart, forming a line pointing to Vega, which is 35° distant; these stars are γ, α, and β Aquilæ, and will easily be identified by their appearance. The southern side of the square in Pegasus also points to them at a distance of three times its length, passing just north of the bright star ϵ Pegasi on the way. The north-west diagonal of the same square will strike (at nearly twice the distance beyond) α Cygni, the lucida of a constellation formed by a zigzag line of bright stars running N.W. and S.E., and representing the wings of a swan flying, while the outstretched head is shown by a third magnitude star, β Cygni, some 20° to the S.W. Continuing our course eastward we get to

Pegasus and Andromeda, already noticed, then we have Perseus, in which there are two bright stars, Algenib and Algol (α and β Persei), of which the former is on a line through β and γ Andromedæ, and thus forms the tip of the tail to the square of Pegasus, whilst β Persei forms the apex of an obtuse angled triangle with γ Andromedæ and α Persei. A line from the square of Pegasus through γ Andromedæ leads to one of the brightest northern stars, Capella (α Aurigæ), with β Aurigæ a little to the east, between which and Boötes there are no very conspicuous stars. Of the southern constellations visible in these latitudes, by far the most striking is Orion, which is on the meridian about ten in the evening in the month of January, lying in the direction of a line from the Pleiades through the Hyades, but there can be no difficulty in identifying this magnificent assemblage of stars, the most beautiful feature in the winter sky. Four bright stars forming a quadrangle represent the shoulders and legs of Orion, Betelgeuse and Rigel (α and β Orionis) at the N.E. and S.W. corners respectively, being both of the first magnitude; the head is indicated by a small triangle of stars, and three second magnitude stars in a diagonal line in the middle of the figure form the belt, which has a dagger of three other stars hanging from it. The line of Orion's belt points to the brightest star in the whole heavens, Sirius, or the Dog Star (α Canis Majoris), though it is too low in these latitudes to be seen in its full splendour, which is something like nine times that of Vega. Another very bright star, though much inferior to Sirius, remains to be noticed, Procyon, or α Canis Minoris, which, with its companion β Canis Minoris, is found by carrying a line from the Pole through Castor and Pollux nearly as far as the equator, where it will be picked up some 25° east of Betelgeuse.

In all that precedes we have followed the constellations in an eastward direction, taking them as they successively came to the meridian, but it must not be forgotten that only a portion of the heavens can be seen at once on any one night, however long we watch; for at any particular season of the year many of the constellations will be above the horizon only in the daytime, and will, therefore, be invisible to the unassisted eye. It will be useful, however, to indicate roughly the principal constellations which will be on or near the meridian at the four seasons of the year about ten o'clock in the evening; if the appearance of the heavens be required for any other hour, it is only necessary to reckon every two hours later in the time we take, as equivalent to taking the positions of the stars for ten o'clock a month later, and conversely for the earlier hours of the evening—thus the positions at midnight in December will be the same as those at ten o'clock in January, whilst the appearance of the heavens at six o'clock will be the same as at ten o'clock in October. Taking ten o'clock in the evening then as our time of observation, we shall have in spring, Regulus on the meridian, Ursa Major directly overhead, the Pleiades and Hyades, Orion and Sirius setting, Capella high up in the west, and Arcturus with the Crown in the east; at midsummer the Crown is on the meridian, with Arcturus a little west of it, and Regulus setting, while Vega, Aquila, and Cygnus are in the east, and Ursa Major in the north-west; in autumn, Pegasus is near the meridian, Vega and Aquila west of it, and Arcturus with the Crown setting, whilst in the east we have Perseus and Capella, with the Pleiades and Hyades rising; at midwinter the latter are on the meridian with Orion and Sirius in the south-east, Pegasus in the west, Cygnus low down in the north-west, with Cassiopeia higher up; Capella is nearly overhead, and in the east are Castor and Pollux, Regulus (rising), and further north Ursa Major. These are only rough indications, but, with what has been given before, they will be sufficient to enable any one to identify the principal constellations, in fact for this purpose it will be enough to remember that about ten o'clock we have on the meridian, in spring, Regulus with its sickle of stars; at midsummer, Arcturus and the Crown; in autumn, the square of Pegasus; and in winter, the Pleiades and Hyades, all at about the position of the Sun at noon in summer.

There is one conspicuous object, the Milky Way, which adds greatly to the beauty of the heavens on a moonless night, especially in autumn. This belt of nebulous light forms an irregular zone with many patches and offshoots, but in the main coinciding with a great circle through the solstices inclined about 60° to the equator. With the telescope this bright band is found to consist of a vast multitude of stars too faint to be individually perceived by the naked eye, and in some cases so close together that a powerful telescope is required to show the separate stars.

Such aggregations of stars are called clusters, and are found of every degree of condensation, but generally circular in form, if the more scattered ones be excluded. Many of them are most beautiful objects even in small telescopes, but powerful instruments are required to show the more compact clusters in all their glory. Among the coarser clusters the Præsepe in Cancer (nearly equi-distant from Castor, Procyon, and Regulus), and one in Perseus at about a third of the distance from δ Cassiopeæ to α Persei, are visible to the naked eye as small nebulous objects, which have been occasionally mistaken for comets by beginners. As we pass to clusters more and more compact, we get by insensible stages to the nebulæ, which are for the most part nothing but clusters, which can only be resolved into stars by the most powerful instruments of modern times. When first attention was directed to the subject, it was thought there was a difference in kind between the clusters and the nebulæ, but as more and more powerful instruments were made, and nebulæ previously held to be irresolvable were separated into their component stars, this idea was gradually abandoned, and the distinction between clusters and most nebulæ became only one of degree. But there were a few nebulæ which still defied even the most powerful telescopes, and the question of the constitution of these objects was left to be settled by the spectroscope, which revealed a spectrum consisting of three bright lines. Now in the third chapter we have already explained that a spectrum of that kind indicates glowing gas, whilst a heated solid gives rise to a continuous spectrum, as in the case of the Sun, of stars, and of the ordinary clusters. These nebulæ, then, cannot be collections of stars, but must



STAR CLUSTER AND NEBULÆ.

be masses of glowing gas, though what that gas is remains an open question.

Two of the nebulæ can be seen by the unassisted eye, one being in the middle of Orion's dagger, where it looks like a blurred star, and the other about a third of the distance from β Andromedæ to β Cassiopeæ. The former of these, which from its spectrum appears to be gaseous, is an irregular shaped mass, without any decided boundary, in the midst of which is a pretty bright multiple star, with others scattered about; whilst the nebula in Andromeda, giving a continuous spectrum, is on the contrary of pretty definite shape, presenting the appearance of a long oval, increasing considerably in brightness towards the centre. This nebula, however, has not yet been resolved into stars, though the spectroscope indicates that it is not composed of gas, unless indeed it be in a very dense state. On the other hand another nebula, which shows the bright lines due to glowing gas, has been resolved into minute points of light, which, however, must be something different from stars in their ordinary state. This nebula midway between β and γ Lyræ is ring-shaped, and one of the most extraordinary objects in the heavens even with a moderate telescope; it is one of a very small class, the elliptical nebulæ being far more common. The planetary nebulæ form another remarkable class, presenting round uniform discs like those of planets, and giving the spectrum of glowing gas; allied to these are the nebulous stars which are occasionally met with. There are also the strange spiral nebulæ, or rather clusters, of which one near the tip of the Great Bear's tail is the finest example; but perhaps the most remarkable objects are the double nebulæ, the finest of which is the "Dumb-bell" nebula in Vulpecula, composed of two oval masses of incandescent gas in contact. Altogether more than 5,000 clusters and nebulæ have been observed, though the vast majority of them are beyond the reach of ordinary instruments. The clusters are almost entirely confined to the Milky Way, whilst the nebulæ appear to avoid this zone, being especially collected in the constellation Coma Berenices and the adjacent parts of Virgo in the Northern hemisphere, and in the two Magellanic clouds in the Southern.

The systems of stars which form the clusters and resolvable nebulæ are found in every stage of condensation, passing from groups like the Pleiades through the globular clusters and oval nebulæ to masses of stars like the spiral nebulæ and others of less regular shape; but there seems to be a break when we get to the gaseous nebulæ, which is to a certain extent explained by Laplace's Nebular Theory. On this hypothesis the solar system was originally a gaseous nebula rotating about its centre, which in the process of condensation assumed something of a spiral structure, each whorl of the spiral forming a sort of ring, which attracted the matter in its neighbourhood, and gradually condensing broke up into several portions. These ultimately coalesced under the influence of their mutual attractions and formed a planet rotating about its axis in the same direction as that of the nebula, since the gas which came from outside the ring would have a greater velocity eastward, and that from inside a less velocity eastward—which, as compared with that of the ring, would be equivalent to a relative velocity westward; so that as referred to the centre of the planet the outer particles would be moving eastward and the inner westward, which is in fact a rotation from west to east. The greatest condensation would take place at the centre, where a large central sun would be formed which would attract to itself nearly all the matter in its neighbourhood, so that only small planets would be formed near it. Nearer the boundary of the nebula the attraction of the central sun would be less felt, and the planets formed there would be able to attract to themselves more of the nebulous matter, becoming themselves centres of smaller nebular systems, from which the satellites would be formed in the same way as the planets in the large nebula, circling in the same direction round a large central planet, such as Jupiter or Saturn. The sphere of attraction of the larger planet being greater, the intervals between the orbits would increase with increasing distance from the Sun, and this would be exaggerated by the decreasing density of the nebula as we proceed outwards.

Though this is only an hypothesis, changes in the solar system of this nature requiring countless ages for their working out, and being therefore beyond the reach of any known methods of observation, it appears highly probable, from what is known of the zodiacal light, that our Sun is really a nebulous star, while the connection between comets and meteors serves to show that phosphorescent gas may readily pass into the form of minute bodies, which are no smaller in proportion to the minor planets than those are as compared with such bodies as Jupiter or Saturn. But though we cannot detect any changes going on in the Solar system, or up to the present time in any of the nebulæ which are supposed to represent its primitive condition, we find changes in going from one nebula to another, which correspond well with what may be supposed to be taking place in any particular nebula in the course of millions of years. Thus there are gaseous nebulæ of various forms, some of them to all appearance physically connected with stars; there are resolvable nebulæ composed of very minute stars, and there are clusters of larger stars in which the process of condensation appears to have been carried a step further, whilst the spectroscope reveals to us stars which seem to be in a transition state, their light being derived from glowing gas, though in this case it is hydrogen, not the unknown substance of the true nebulæ. But we must not push the analogy between our system and the nebulæ and clusters too far, for there are points of difference, and it would seem more probable that ours is only a secondary system, forming part of some enormous cluster.

This much, however, is tolerably certain, that our Sun is really one of the stars, and that the earth and other planets would be all but invisible even from the nearest of them, careful observations showing that the earth's orbit at that distance is apparently less than 2″ across. If, then, we view the star from opposite points of the earth's path, there will be this small shift of 2″, and this is our only means of finding the star's distance, for clearly any parallax from different stations on the earth will be quite insensible. It is not necessary that the two observations at opposite parts of the earth's orbit should be made at the same time, which would evidently be impracticable, but it is sufficient to determine very carefully the star's position, and then to wait six months, when the earth's motion will carry us to the other side of her orbit; the shift of a star caused by this motion of the earth in her orbit is called annual parallax, representing the difference between the positions of the star as seen from the Sun and earth, and may be determined in two ways:—1. By measures of absolute right ascension and declination; 2. By measures of angular distance from neighbouring stars. The first method is liable to errors as large as the quantity we are seeking, but it has been applied with success to the bright Southern Star α Centauri, giving an annual parallax of 1″—the largest yet found—the whole shift for opposite parts of the earth's orbit being 2″, corresponding to a distance 200,000 times that of the Sun, or about 7,000 times that of Neptune. The only satisfactory way of expressing this enormous interval, which separates us from the nearest fixed star, is by a reference to the velocity of light, which, travelling at the rate of 186,000 miles in a second, takes 3¼ years to reach us, having passed Neptune only 4 hours before. Thus in looking at this star we only see its state 3¼ years ago, and this, be it remembered, is the nearest fixed star! The second method may be compared to the determination of the distance of Venus by means of her transit across the Sun, the relative shift being measured; but in that case we know the relative distances, whilst with the stars all we can do is to select such stars for reference as we consider to be probably at a far greater distance than the star in question. Thus if two stars be nearly in a line, but one of them far behind the other, they will be seen apparently close together, and a shift in our position will alter the apparent distance between them, bringing them more nearly in a line or throwing them further out. In any case, if such a shift be found, we know that the earth's orbit must appear of *at least* this size as seen from the star which is shifted, so that the distance cannot be more than would correspond to this, and may be considerably less. The following list gives the parallax of the stars in which any shift has been observed, together with the magnitude of the star, from which it will be seen that the brightest stars are by no means the nearest to us in all cases:—

FIRST METHOD.	MAG.	ABSOLUTE PARALLAX.	JOURNEY OF LIGHT IN YEARS.
α Centauri	1	0″·9	3⅔
β Centauri	1	0·5	6½
Procyon	1	0·2	16
Arcturus	1	0·2	16
Groombridge 1830	6½	1·0 (?)	3¼ (?)
SECOND METHOD.		RELATIVE PARALLAX.	
61 Cygni	5½	0″·4	8
η Cassiopeæ	4	0·4	8
Lalande 21258	8½	0·25	13
Oeltzen 17415	9	0·25	13
Vega	1	0·2	16
Sirius	1	0·2	16
70 Ophiuchi	4½	0·2	16
Polaris	2	0·1	32
Groombridge 1830	6½	0·1 (?)	32 (?)

In the case of the smaller parallaxes the results are very uncertain; and this is especially so with Groombridge 1830, for which a negative parallax relatively to one star in its neighbourhood has been found, indicating that the star in question is nearer to us than Groombridge 1830—but not much confidence is to be placed in this result.

It may seem strange that some of the small stars given above should have been selected for observation, but attention was called to them by the discovery that they were moving among the other stars at a rate which, though very small, was far greater than that of most other stars, from which it was concluded that they were probably much nearer to us. This statement may startle a reader who is used to the phrase fixed stars, but really the motion is so small that very accurate observations, separated by a long interval, are required to detect it, and the term fixed may still be applied to the stars in contradistinction to such bodies as the planets. The largest proper motion found among the Northern stars is that of Groombridge 1830, and this is only 7″ a year, at which rate it would make a complete tour of the heavens in 180,000 years if its motion continued uniform; the double star 61 Cygni has a proper motion of 5″ a year, and many other stars have shown smaller, though still sensible motions, there being apparently every variety of motion, as there is every gradation of brightness. As, in the case of 61 Cygni, the radius of the earth's orbit at the distance of that star is 0″·4, the star must annually move over about 12 times the distance of the Sun from us, from which it follows that it is moving with four times the earth's velocity, or at the rate of about 70 miles a second. So many of the stars appear to have motions of their own, that it seems natural to suppose that our Sun too may be in motion, carrying our earth and all the planets with him, one consequence of which would be to make all the stars appear to move in the opposite direction; and this furnishes a ready test of the supposition, for it is only necessary to see whether there is any general drift of the stars which could be accounted for by a motion of the Sun the opposite way. Over 2,000 stars have been examined, and in the midst of much variety (as was to have been expected) there is found a general preponderance of motions away from the constellation Hercules, towards which the Sun, therefore, appears to be moving. Although most of the stars move, as nearly as we can tell, uniformly in the same direction from year to year, there are a few exceptions, the most remarkable being Sirius, which is found to describe an ellipse about a point at a mean apparent distance of 2½″ in something like 50 years, and Procyon, which revolves in 40 years nearly in a circle, having an apparent radius of 1″. Such a motion would result from the attraction of another body, and in accordance with this supposition a small star has been found some 10″ off, which revolves round Sirius somewhat as the Moon does round the earth (but at a distance greater than that of Neptune from the Sun), whilst Sirius describes in space an ellipse about the centre of gravity of the two. As the distance of these two is greater than that of Neptune from the Sun, whilst their year is much less, the attracting force between them must be much greater, and by reasoning similar to that used in finding the Sun's mass in terms of that of the earth (Chapter IV.), it follows that the attracting masses must be some 18 times that of the Sun and Neptune (the latter of which is comparatively small), and the centre of gravity being twice as far from the companion as from Sirius, the mass of the latter must be about twice as great, or some 12 times that of the Sun. This can only be looked upon as a rough approximation, the numbers being extremely uncertain. In the case of Procyon a similar companion star has been detected, which may prove to be the disturbing body.

The two stars above-mentioned are rather peculiar examples of a very numerous class—stars revolving about each other. In a powerful telescope a large number of stars which are apparently single to the naked eye are seen to be composed of two, and sometimes three or more stars very close together, a sufficiently remarkable circumstance considering how thinly the bright stars are scattered; and the interest in these objects has been enhanced by the discovery that in many cases each star is revolving round the other, forming what is called a binary system. From observations of the apparent direction of one star of such a system relatively to the other, combined with measures of the apparent distance between them, extending over many years, the paths of a good many have been determined; some of these are given in the following list, with the magnitudes of the two stars, their least and greatest distance apart, and the period in years:—

STAR.	MAG.	DISTANCE.		PERIOD IN YEARS.	COLOURS.
		MIN.	MAX.		
		″	″		
ζ Herculis......	3, 6	0·7	1·8	35	Yellowish and orange.
η Coronæ.......	6, 6½	0·7	1·2	44	White and golden.
ζ Cancri......	6, 7	0·6	1·2	62	Triple; all white.
	7½,	5·2	5·8	700	
Procyon.......	1, 12	12·0?	12·0?	40	White.
Sirius..........	1, 10	3·0	11·0	50	White.
ξ Ursæ Majoris	4, 5½	1·5	3·5	60	White.
α Centauri......	1, 2	1·0	60·0?	75	
70 Ophiuchi	4½, 7	2·4	6·0	90	Yellow and violet.
δ Cygni	3½, 9	0·7	2·9	180	Yellow and sea green.
η Cassiopeæ....	4, 7½	2·6	18·0	180	Doubtful.
γ Virginis	4, 4	0·4	6·8	180	White and pale yellow.
Castor	3, 3½	4·7?	7·8	600 ?	White.
61 Cygni.........	5½, 6	15·5	?	450 ?	Yellow.
γ Leonis	2, 4	2·6	?	1000	Doubtful.
ε² Lyræ..........	5, 5½	2·5		1000	White.
ε¹ Lyræ	5, 6½	3·0		2000	Yellow and ruddy.

The parallax of some of the above stars has been determined, from which, as in the case of Sirius, the combined mass of the two stars of α Centauri has been found to be ⅘ of the Sun's mass; of 61 Cygni about $\frac{2}{5}$; and of 70 Ophiuchi about 8 times that of the Sun. ϵ^1 and ϵ^2 Lyræ form a double binary system, visible to the naked eye, under exceptionable circumstances, as a very close double star near Vega, forming part of the pendent to the lozenge of Lyra, and ζ Cancri is a ternary system.

Besides the binary stars, there are others between which a physical connection has not yet been established, and which may therefore *possibly* be composed of two stars only *optically* double, one star being nearly in a line with the other, but much further off. Some of these are most interesting objects from the beautiful contrast of colours in the two stars. The following may be selected as worth notice:—

STAR.	MAGNITUDES.	DISTANCE.		COLOURS.
β Cygni........	3, 7	34″	Double	Golden and smalt blue.
α Herculis.....	3½, 5½	4½	Double	Orange and emerald green.
ϵ^2 Boötis.......	3, 7	3	Double	Orange and blue.
Polaris......	2½, 9½	19	Double	Yellow and bluish.
γ Andromedæ	3½, 5½, 6	10, 0″·5	Triple	Yellow and sea green.
β Lyræ.........	3½, 8, 8½, 9	46, 60, 70″	Quadr.	White.
σ Orionis......	4, 8, 7	12, 42	Triple	White, bluish, grape-red.

From the evidence of the spectroscope it appears probable that difference of colour in the stars corresponds in a general way to a difference of condition, the stars being divided broadly into three classes.

1. White stars, like Vega, at a very high temperature, and exhibiting a continuous spectrum with very fine absorption lines.
2. Yellow stars (like our Sun, Arcturus, Betelgeuse) at a lower temperature, showing strong absorption lines in a continuous spectrum.
3. Red stars, in which the temperature is so low that combination of the elements in their atmosphere takes place, and compound molecules are formed, showing a spectrum with broad absorption bands.

In some of the stars of the first and second classes the lines of hydrogen appear bright in the spectrum, indicating a huge conflagration of this gas, whilst with other stars, like our Sun, the hydrogen is at a lower temperature, and absorbs more light from the photosphere than it emits, causing dark lines in the spectrum. To such conflagrations the appearance of temporary stars, such as were seen in 1572, 1604, 1670, 1848, and 1866, appears to be due. On all these occasions bright stars burst suddenly on the view, and after a short time disappeared more or less completely. Thus in 1866 a telescopic star in Corona suddenly appeared of the second magnitude, fading away in 12 days to the 8th or 9th magnitude; and the star of 1572 was even more remarkable, at one time surpassing Jupiter in brightness.

The temporary stars are only extreme instances of a much wider class, the variable stars, in which are found changes of all kinds, extending over periods which range from nearly three days to an indefinite length, the variations of brightness recurring in some cases with the greatest regularity, whilst in others the changes seem to follow no definite law. Among the former are β Persei (Algol), which is ordinarily of the second magnitude, but at intervals of 2 days 21 hours diminishes to the fourth magnitude, and increases again to the second, all within the space of 7½ hours, λ Tauri, which changes from 3½ to 4 magnitude in 4 days, δ Cephei from 3⅔ to 5 magnitude in 5⅓ days, and β Lyræ fluctuating between 3½ and 4½ magnitude twice in 12 days 21 hours. The star ο Ceti (known as Mira) goes through its changes in about 11 months, but is very irregular as regards their extent, which sometimes ranges from brighter than the second magnitude to below the twelfth. The Southern star η Argus is another remarkable variable, changing from first to sixth magnitude in an irregular period; α Orionis, α Herculis, α Hydræ, β Pegasi, η Pegasi, and α Cassiopeæ, are also irregularly variable, sometimes to the extent of half a magnitude or more, and many less conspicuous stars have been noted as variable. Nearly all these stars are orange or red, and changes in colour have in several cases been suspected, which would seem to show a change of temperature as they passed from a red to a white heat. Some of the double stars too are thought to have changed colour, but accurate observations on this point are yet wanting, the eye alone being quite untrustworthy for absolute determinations of colour.

We saw that, when observations made at wide intervals came to be compared, many of the so-called fixed stars were found to be really in motion; but this is not the only startling result. The Pole of the heavens is also found to be moving among the stars, very slowly, it is true, but still quite perceptibly. It will be remembered that all right ascensions and longitudes of stars, are measured from the point where the Sun crosses the equator, so that if the point shifts, the right ascensions and longitudes of all objects will be altered, and this is found actually to be the case, the longitudes of all stars increasing at the rate of about 50″ a year on account of a shift westward of the equator along the ecliptic, which is known as the precession of the equinoxes. A clearer idea of this motion will be gained by considering the pole instead of the equator, which of course always moves with it. The pole of the heavens, then, is found to be at any instant describing a very small arc of a circle about the pole of the ecliptic (which has itself a very small motion) at a rate which would carry it completely round in a circle of about $23\frac{1}{2}°$ radius in some 26,000 years. Now the pole of the heavens is nothing but the direction of the earth's axis, which it appears has not really a fixed direction in space, though in explaining the phenomena of the seasons it was unnecessary to take account of such a very small motion. Instead, then, of the earth's axis pointing always *exactly* in the same direction, it is circling round like a top, and from somewhat the same cause. The Sun and Moon pull the near part of the earth's equator (which bulges out) more than the other part (as in the case of the tides); but as the earth is spinning rapidly, the effect of this is not to bring the equator into the direction of the Sun and Moon, *i.e.*, the ecliptic, but to make the earth's axis circle round the axis of the ecliptic, just as a gyroscope top hanging by a string on one side keeps a horizontal position, its axis turning round horizontally so long as it is spinning rapidly, though the attraction of gravity makes it hang straight down when at rest. This analogy will remove the difficulty of conceiving how such a seemingly paradoxical result could follow. In the case of the top, its weight tends to make it turn about a horizontal axis at right angles to its own (just as a hinged flap would in falling), and the combination of this with its own rotation causes it to turn about an axis between the two, thus making the axis, about which the top spins, move continually forward; for there is at every instant a tendency (in consequence of the action of gravity) to turn about an axis a little in advance of the actual axis. Similarly the Sun and Moon tend to turn the earth about the intersection of the equator with the ecliptic as an axis, which, combining with the actual rotation, makes the earth spin about an axis a little towards the autumnal equinox, so that the pole of the heavens (being the direction of the earth's axis) moves a little towards the autumnal equinox, thus describing a very small arc of a circle about the pole of the ecliptic. Besides this regular recession, the earth's axis has a wabbling motion depending on the inclination of the Moon's orbit, causing the pole of the heavens to move really in a wavy line, each wave extending over nineteen years (lunar nutation); and there are other irregularities modifying slightly, though not destroying, the regular precession, which has carried the equinoxes through 30° along the ecliptic since the first catalogue of stars formed by Hipparchus in B.C. 125, increasing the longitudes of all stars by this amount.

This has introduced some confusion between the constellations and the signs of the zodiac, as the twelve parts into which it is divided, are called. In the time of Hipparchus the vernal equinox corresponded to the commencement of the constellation Aries (reckoning from the west), and was hence called the first point of Aries, whilst the autumnal equinox was the first point of Libra, and the summer and winter solstices were in Cancer and Capricorn respectively; but though the equinoxes have now moved to the constellations Pisces and Virgo, it is convenient to retain the old terms, and thus a distinction has arisen between the constellations and the signs of the zodiac, the former preserving their positions among the stars, whilst the latter shift with the equinoxes, the sign Aries being now in the constellation Pisces, the sign Taurus in Aries, and so on. The practice, however, of referring the positions of the sun and planets to the signs af the zodiac has died out with the increase in the accuracy of observations, as the rough correspondence between the twelve signs and the twelve months of the year is no longer close enough even for the purposes of ordinary life.

ELEMENTS OF THE PRINCIPAL PLANETS.

Symbol.	Name.	Distance from Sun (in terms of Earth's Mean Distance).		Period in Solar Days.	Velocity in Orbit.	Tilt of Orbit to Ecliptic.	Diameter (in terms of the Earth's).	Apparent Diameter.		Density.	Rotation.
		Greatest.	Least.		Miles a Second.			Greatest.	Least.		
☉	Sun	...	...	...	...	° ′ ...	108	32′.36″	31′.32″	0·25	d. 25⅓
☿	Mercury ...	0·466	0·308	88	29¼	7.0	0·4	11·5	4·5	1·14	?
♀	Venus	0·728	0·718	225	21⅓	3.23	0 95	1. 2·0	9·5	0·84	h. m.
⊕	Earth	1·017	0·983	365¼	18⅕	0.0	1 0			1·00	24.0
♂	Mars.........	1·666	1·382	687	14¾	1.51	0·6	23·5	3·3	0·72	24.37
♃	Jupiter......	5·454	4 952	4333	8	1.19	11·2	46 0	30·0	0·24	9.55
♄	Saturn......	10·075	9·003	10759	6	2.30	9 1	20·5	14·6	0·11	10.29
♅	Uranus......	20·077	18·287	30687	4⅖	0.46	4 2	4·3	3·5	0·20	?
♆	Neptune ...	30·298	29·774	60126	3⅓	1.47	5·0	2·7	2·6	0·15	?

ELEMENTS OF PERIODICAL COMETS.

Comet.	Period in Years.	Distance.		Direction of		Tilt.	Last Appearance.
		Least.	Greatest.	Long axis.	Node.		
Encke..................	3·3	0·3	4·1	158°	335°	13°	1875, April.
Brorsen	5·5	0·6	5·6	116	101	29	1873, Oct.
Winnecke............	5·6	0·8	5·5	276	114	11	1875, March.
Tempel	6·0	1·3	5·3	238	79	10	1873, May.
D'Arrest...............	6·6	1·3	5·7	319	146	16	1870, Sept.
Biela	6·6	0·9	6·2	109	246	13	1852, Sept.
Faye	7·4	1·7	5·9	50	210	11	1866, Feb.
Tuttle..................	13·8	1·0	10·5	116	269	54	1871, Nov.
Halley	76·4	0·6	35·4	305	56	17	1835, Nov.

The distance is expressed in terms of the earth's distance from the Sun, the direction (or longitude) measured from the Vernal Equinox of the Long axis and of the Node refers to the end of the Long axis nearest the Sun and to the ascending Node (from south to north as the comet moves). All the periodical comets except Halley's move in the same direction as the planets.

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