Transit of Venus.

December 8, 1874.

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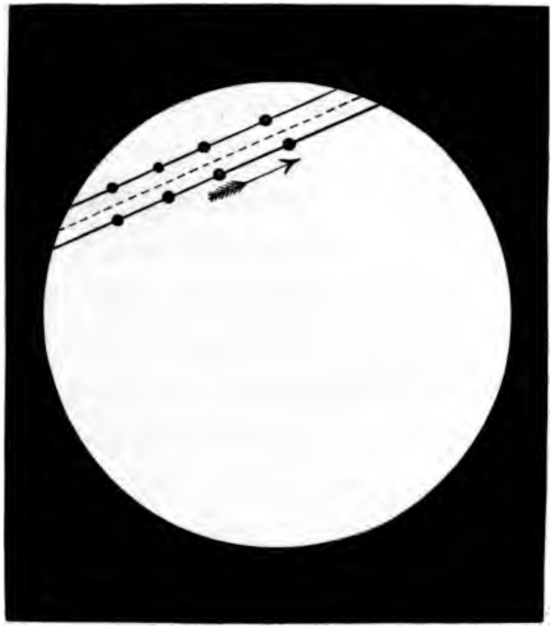
PUBLISHED BY

JAMES MACLEHOSE, GLASGOW.

MACMILLAN AND CO., LONDON.

Edinburgh, . . . *Edmonston & Douglas.*
Dublin, ... *W. H. Smith & Son.*

DECEMBER 9, 1874.



TRANSIT OF VENUS, 1874.

THE TRANSIT OF VENUS

IN 1874.

BY

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GLASGOW: JAMES MACLEHOSE,
PUBLISHER TO THE UNIVERSITY.
LONDON: MACMILLAN AND CO.
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According to the science of modern astronomy, the Sun occupies the centre of the planetary system, and the Earth is a planet, revolving round the Sun like the other planets of the system; on the other hand, the innumerable stars are supposed to be situated in space at a remote distance apart from the planetary system. But the Earth is a round body several thousand miles in diameter. We may therefore reasonably infer that the other planets are similarly bodies of vast dimensions, and this conclusion applies with still greater force to the Sun, the central body of the planetary system. Furthermore, the theory of modern astronomy, which places the Sun in the centre of the planetary system, assigns to the stars of the celestial vault the *rôle* of so many resplendent suns, each constituting the centre of a retinue of revolving bodies. In like manner, then, as we are led to suppose that the Sun is a body of great magnitude, so we infer, by a similar train of reasoning, that the stars are also bodies of vast dimensions.

But in order to ascertain the magnitudes of the celestial bodies, we must know their distances from the Earth. We are thus led to consider the supreme importance of the astronomical problem which is to form the groundwork of our explanations. When we have once made some progress in a knowledge of the distances of the celestial bodies, we are in a position to form a conception of the amazing extent of the physical universe. We thus come to learn that the Sun is a stupendous globe more than 800,000 miles in diameter, and that its distance from the Earth is more than ninety-one millions of miles. We learn, furthermore, that the planets are bodies of immense size revolving round the Sun, that the extreme planet of the system, the planet Neptune, revolves at a distance of two thousand eight hundred millions of miles from the central body, and that the orbits of many comets extend even much farther into space. Finally, we arrive at the conclusion that the stars are in reality suns, exceeding in many instances the great central body of the planetary system in magnitude, and traversing space at an almost inconceivable distance from the Earth.

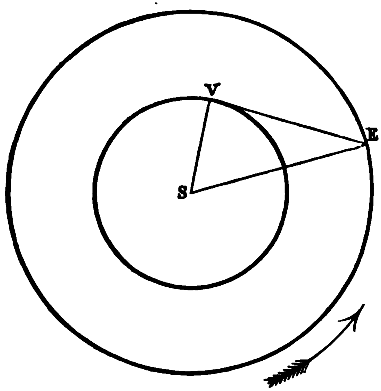
Researches of the Ancient Astronomers on the Distances of the Celestial Bodies.

THE Greek astronomers made some ingenious attempts to determine the distance of the Sun from the Earth, but in no case was either the method of solution or the existing state of astronomy adequate to meet the requirements of a problem of such difficulty. In the case of the Moon they were more successful. The method employed by them was exactly the same in principle as that used by modern astronomers, and forms indeed the basis of all researches having for their object the determination of the distances of the celestial bodies from the Earth. A brief explanation of it will presently be given.

Relation between the Mean Distances of the Planets from the Sun, and their Times of Revolution round that Body.

It is a remarkable fact that although the ancient astronomers made no progress in the determination of the absolute distances ot the celestial bodies from the Earth, with the single exception of the Moon, they arrived at a very approximate estimate of the relative distances of the planets from the Sun. Ptolemy, who is, next to Hipparchus, the greatest astronomer of antiquity, has given a statement of the relative distances of the planets in a very important work which he has written on the science of astronomy; and those results, after receiving a correction derived from the observations of the Danish astronomer, Tycho Brahé, were instrumental in conducting

Fig. 1.



the renowned astronomer Kepler to one of the greatest discoveries recorded in the annals of science. Fig. 1 shows how the relative distances of Venus and the Earth from the Sun may be readily derived from observation. S represents the Sun, E the Earth, and V Venus. The time chosen for the observation is that at which the angular distance of the planet from the Sun is the greatest possible. The angle SVE being then a right angle, it suffices to determine by observation the magnitude of the angle SEV in order to ascertain the proportion of SE to SV, which gives the relative distances of the Earth and planet from the Sun.

With the view of enabling the reader to form an idea of the importance of the discovery of Kepler above alluded to, we shall now lay before him a statement of the times of revolution of the eight principal planets, and their relative distances from the Sun, as derived from the most recent researches :—

	Time of Revolution.	Mean Distance.
Mercury, ...	0·241	0·388
Venus, ...	0·615	0·723
The Earth, ...	1·000	1·000
Mars, ...	1·884	1·524
Jupiter, ...	11·868	5·203
Saturn, ...	29·456	9·539
Uranus, ...	84·014	19·182
Neptune, ...	164·610	30·037

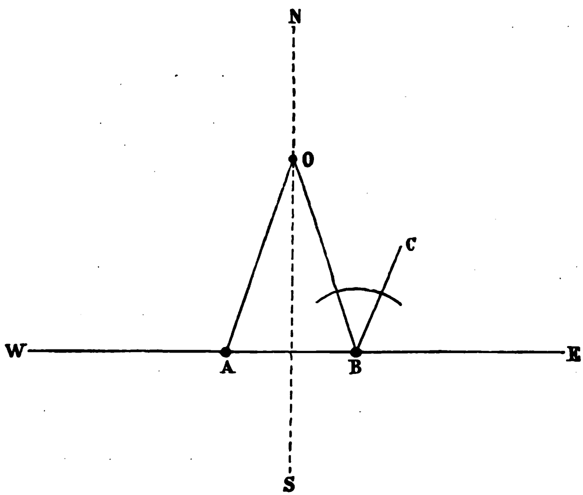
It will be readily seen from this table that, as the time of revolution of a planet increases, its mean distance from the Sun increases also. It is manifest, however, that the mean distance increases in a much slower proportion than the time of revolution. Thus, while the time of revolution of the planet Neptune exceeds the time of revolution of the Earth in the proportion of 164 to 1, the mean distance of Neptune exceeds the mean distance of the Earth only in the proportion of 30 to 1. It was reserved for Kepler to discover a relation between the times of revolution and the mean distances of the planets, by means of which one of these elements can be readily ascertained from a knowledge of the other. This theorem is generally called Kepler's third law of the planetary movements. It may be thus enunciated: —*The squares of the times of revolution of the planets are proportional to the cubes of their mean distances from the Sun.* The significance of this law will be readily understood by a reference to the foregoing table. Thus, to take the case of the planet Mars—its time of revolution is 1·884, the square of which is 3·53; again, its mean distance is 1·524, the cube of which is 3·53, a result exactly equal to the square of the time of revolution. In the same way, if we take any other planet, and if we square the time of revolution and cube the mean distance, we shall obtain two sets of numbers which will be identical, or very nearly identical, with each other. Furthermore, it is plain from this law that, if we know the time of revolution of a planet, we have only to square it, and we obtain a result, the cube root of which will give the mean distance of the planet from the Sun. Conversely, if we know the mean distance, we have only to form the cube of it, and the square root of the result will give the time of revolution.

It is important to bear in mind that in the table which we have given representing the times of revolution and mean distances from the Sun of the principal planets, it is only the *relative* distances which are set down. Thus we learn from the table that the mean distance of Jupiter is 5·203—the Earth's mean distance being represented by unity; but the table gives us no information respecting the absolute value of this unit. It is clear, however, that if we assign a certain numerical value to it, we are then in a position to determine the absolute numerical value of the mean distance of any planet from the sun. Thus, if the unit be expressed by ninety-one and a half millions of miles, this number will then represent the absolute mean distance of the Earth from the Sun; and similarly the mean distance of Jupiter, as given in the table, upon being multiplied by ninety-one and a half millions of miles, will give, in round numbers, four hundred and seventy-six millions of miles as the absolute mean distance of the planet from the Sun. We thus learn the supreme importance of ascertaining the *absolute* mean distance of any one planet from the Sun; for this object being once achieved, the mean distances of all the other planets from the Sun may be readily computed by an arithmetical process, either from the table of relative distances, or by means of Kepler's third law.

Explanation of the Method for Finding the Distance of an Inaccessible Object.

THE determination of the distance of an inaccessible object appears to many persons to be an undertaking of insuperable difficulty. Nothing can be more simple than the principle which underlies the solution of this problem. Let A represent the position of an observer who wishes to ascertain his distance from an inaccessible object O. He first carefully measures the distance between the station A and another station B. The line thus measured is called a *base line.* With a theodolite he then measures the bearing of O relatively to the station B. He next

Fig. 2.



proceeds to the station B, and similarly measures the bearing of O with respect to the station A. In this manner he determines the two angles at the base of the triangle AOB, and having already ascertained by measurement the length of the base AB, he is in a position to compute the remaining sides and angles of the triangle. He thus arrives at a knowledge of the lengths of the lines AO, BO, which represent the distance of the object from each of the two stations.

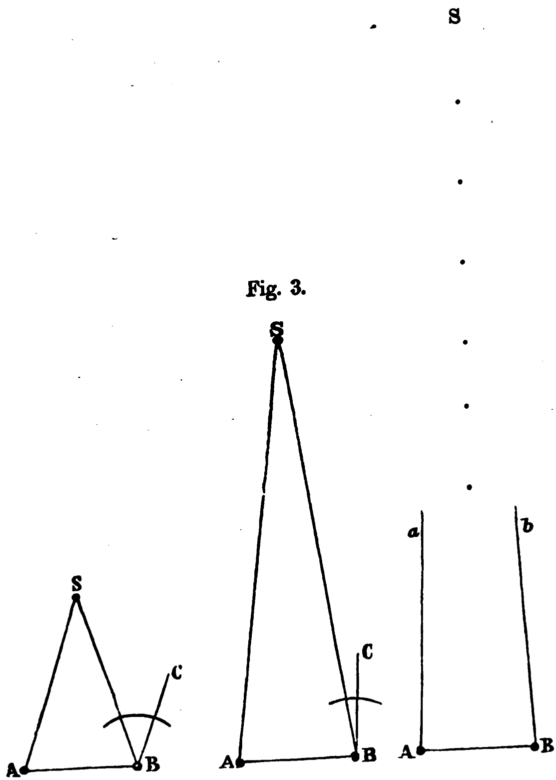
In Fig. 2, the letters S, E, N, W, denote the cardinal points of the horizon, South, East, North, West. Now it is clear that when the object O is viewed from A, it appears in the direction *north-*

east; on the other hand, when observed from B, it appears in the direction *north-west*. The angle AOB, formed by the lines AO, BO, indicates therefore the *change of direction* which the object undergoes in consequence of the observer shifting his position from A to B. It has received an important designation. It is called the *parallax* of the object.

Difficulty experienced in Applying the foregoing Principle to the Celestial Bodies.

In endeavouring to ascertain the distances of the celestial bodies by the application of the principle explained above, we at once encounter a grave difficulty.

Fig. 3.

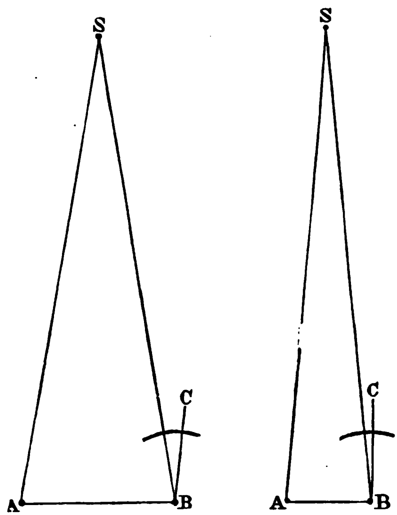


In Fig. 3, let S, S, S, represent a celestial body at different distances from a base line AB of *invariable length.* The parallax of the object is obviously represented by the angle SBC, formed by drawing BC parallel to AS. Now, it is clear, by an inspection of the figure, that the more distant the object is, the smaller does the angle of parallax become, insomuch that finally the distance of S may be so great that the line drawn parallel to AS coincides sensibly with BS, and the angle of parallax vanishes altogether. Now, if we fail to determine the angle at S, which represents the parallax of the object, we have no means of solving the triangle ASB, and consequently we are unable to ascertain the value of the distance AS or BS.

We have hitherto supposed the base line to be invariable. Let us now consider what would be the effect produced by assigning to the base line a *variable* length, and placing the celestial object S at the same constant distance. It is manifest, by referring to Fig. 4, that as the base line diminishes the angle of parallax diminishes also, insomuch that finally we may imagine S to be so remote that the line BC, drawn parallel to AS, coincides sensibly with BS, and the angle of parallax vanishes altogether.

We now perceive clearly the main source

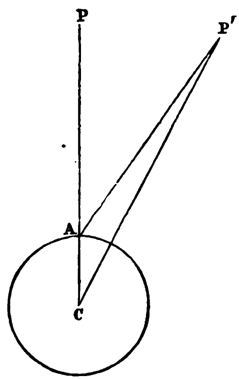
Fig. 4.



of the difficulty experienced in determining the distances of the celestial bodies from the Earth. It arises in the first place from the extreme remoteness of those bodies, and secondly from the comparative smallness of the base from which they are measured. The Earth is a body of only eight thousand miles in diameter; consequently any base line drawn on its surface cannot possibly exceed a few thousand miles in length. This, however, is an insignificant magnitude compared with the immense distance of the celestial bodies. In consequence of this circumstance the parallax of a celestial object is so excessively small that, until towards the close of the seventeenth century, its determination even approximately in any case, with the single exception of the Moon, had steadily continued to baffle the efforts of astronomers.

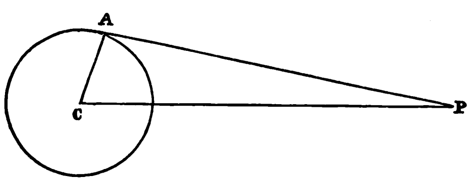
In observing the celestial bodies, it is usual for astronomers to refer their apparent positions to the centre of the Earth which is the true physical centre of the terrestrial globe. Indeed, since the Earth is a body of considerable dimensions, it is plain that observations made from different places on its surface could not be comparable unless they were referred to some common centre. In Fig. 5 let P, P′, be two celestial bodies ; A the position of an observer on the Earth's surface, and let C denote the centre of the Earth. P is supposed to be in the zenith ; consequently P′ is supposed to be

Fig. 5.



removed from the zenith by the angle PAP′. Now, the object P being in the zenith, occupies the same apparent position when viewed from A, as it would do if seen from the centre of the Earth. The object P′, on the other hand, when viewed from A, is displaced relatively to the Earth's centre by the angle AP′C. This angle is called the diurnal parallax of the object. While the parallax vanishes for an object in the zenith, it attains its maximum value for an object which is in the horizon, as

Fig. 6.



in Fig. 6, which exhibits the horizontal parallax P, namely, the angle APC.

It appears then that, in order to determine the distance of a celestial body from the Earth, two things are necessary. First, we must know the exact length of the base line from which the observations of the object are made ; secondly, we must detect an appreciable parallax of the object depending upon the observations made at the two extremities of the base. As regards the base line, we are enabled to compute its length exactly when we once know the magnitude and figure of the Earth, and the longitude and latitude of each of the two extremities of the base. The measurement of the angle of parallax is manifestly an operation of much delicacy, in consequence of its extreme minuteness; for, except under exceptionally favourable circumstances, it eludes the efforts of the most skilful astronomer.

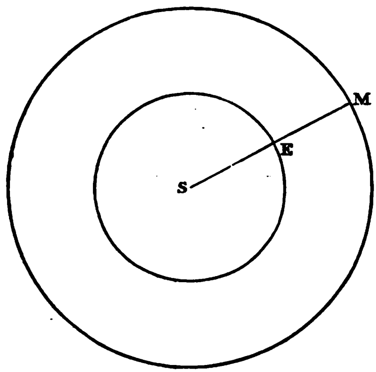
It has been already stated that, if we once ascertained the absolute distance of any one of the planets from the Sun, the table of relative distances would enable us to compute the absolute distances of all the others. Now, the Earth being a planet, it is clear that we could effect this important object if we succeeded in determining the exact value of the solar parallax. We now begin to perceive the immense magnitude of the results derivable from a knowledge of this element.

To ascertain the value of the solar parallax by direct observations of the Sun has been found impracticable for various reasons, which it would be out of place to attempt explaining here. Instead of attacking the problem in this way, astronomers have skilfully evaded its more formidable difficulties by deducing the value of the solar parallax from observations of certain of the planets. It is clear from what has been already stated that the nearer a planet is to the Earth the more favourable are the circumstances for the determination of its parallax.

Now, there are two planets which occasionally approach comparatively near to the Earth. These are the planets Venus and Mars—the one revolving immediately within the Earth's orbit, the other revolving immediately beyond it. We shall commence with a remark or two on Mars, which was the planet first employed for determining the solar parallax.

Fig. 7 represents the orbits of the Earth and Mars, on the supposition that they are both circles, having the Sun in their common centre S. Let the Earth be travelling in its orbit at E; join SE, and imagine it to be extended so as to meet the orbit of Mars in M. Now it is plain that when the planet is

Fig. 7.

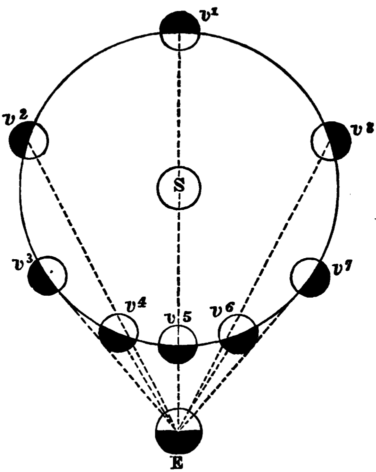


at M, it is nearer to the Earth (supposed for the sake of explanation to be always at E) than when it is in any other part of its orbit. In this position the planet is technically said to be in *opposition*, the reason being that when viewed from the Earth it then appears in the *opposite* region of the heavens to that in which the Sun is situate. Thus, if at the time when the planet is in opposition it is midnight, the Sun being then due *north* and *under* the horizon, the planet will appear due *south* and *above* the horizon. It is obvious therefore that when the planet is in opposition it is much nearer to the Earth than when it is in any other part of its orbit. But in point of fact the circumstances are much more favourable than we have imagined. We have assumed that the orbits of the Earth and the planet are both circles. In reality, however, they are ellipses. The orbit of Mars is considerably excentric; that of the Earth is less so: but the two orbits are so placed relatively to each that their excentricities combine together in producing occasionally a comparatively near approach of the two planets. Thus, when the planet is in the *perihelion*, and consequently in the position where it is *nearest possible* to the Sun, and if it be at the same time in opposition, the Earth will be very near the *aphelion* of its orbit, and consequently will be the *farthest possible* from the Sun. In this position then the planet will as it were *retire* (within its supposed circular orbit) to meet the Earth, while the Earth will advance outwards (beyond its supposed circular orbit) to meet the planet. The consequence of this favourable state of matters is that, while in general the distance between the Earth and planet at the time of opposition amounts to fifty or sixty millions of miles, it occasionally diminishes so as not to exceed thirty-five millions of miles. This near approach of the two planets happens at intervals of fifteen or seventeen years. It was first taken advantage of for determining the solar parallax in the seventeenth century by Cassini, an eminent

French astronomer, who obtained 9″·5 for the value of the solar parallax, whence the distance of the Sun from the Earth would be eighty-five millions of miles. This method of determining the Sun's distance from the Earth has been used on several subsequent occasions.

But the planet Venus furnishes a method of a peculiar kind for ascertaining the value of the solar parallax, which has been considered to be more entitled to confidence than any other method heretofore employed for the purpose. This beautiful planet, as has been already stated, revolves immediately within the Earth's orbit. Fig. 8 gives a graphic representation of the various positions which it assumes as it revolves

Fig. 8.



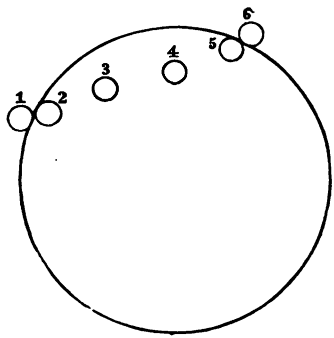
round the Sun, the Earth being assumed, for the sake of illustration, to be stationary at E. When the planet is at v^1, it is then immediately beyond the Sun, and the Earth, Sun, and planet are in the same straight line. In this position the planet is said to be in superior conjunction. The illuminated hemisphere being turned wholly towards the Earth, the planet, if it were possible to see it, would present a round disc, like the full Moon. It is, however, immersed in the effulgence of the Sun's light, and is consequently invisible. In this position both Sun and planet rise and set together. As the planet revolves in its orbit, the illuminated hemisphere is gradually turned away from the Earth, and the planet assumes a gibbous aspect, as at v^2; it also now begins to set after the Sun, and is therefore an evening star. At v^3 it assumes the appearance of the half moon; the time of its visibility above the horizon after sunset is also now the longest possible. In this position the planet is said to be at its greatest eastern elongation. After quitting this position the planet assumes the form of a beautiful crescent, as at v^4; it also now gradually approaches the Sun, continuing a shorter time above the horizon on each successive night. When the planet arrives at v^5, the Sun, Earth, and planet are again in the same straight line. The planet is now said to be in inferior conjunction. In this position it comes directly between the Sun and the Earth. The Sun and the planet now rise and set together. When the planet has advanced beyond this position it rises and sets *before* the Sun, and is, consequently, now a *morning* star; and the same succession of phases is reproduced in a reverse order, until the planet finally arrives in superior conjunction at v^1, when both Sun and planet again rise and set together.

Now, it is clear from this explanation that when the planet is in inferior conjunction, it is nearer to the Earth than in any other part of its orbit. The occasion is therefore especially favourable for the determination of its parallax. But, unfortunately, the same cause which prevents the planet from being generally visible, when it is in superior conjunction, is equally efficacious in this case also. There are, however, certain rare occasions when the planet may be seen in this position, not however as a *star*, but as a *round black spot* passing over the Sun's disc. Since Mercury and Venus both revolve within the Earth's orbit, they may occasionally be seen in this manner between the Earth and the Sun. A phenomenon of this kind is technically termed a *transit* of the planet. The importance of the transits of Venus over the Sun's disc for ascertaining the value of the solar parallax was first pointed out by James Gregory, and was afterwards insisted upon more fully by Halley. In 1761 and 1769 there occurred transits of Venus over the Sun's disc, and in both cases, the occasion was deemed to be of so great importance that the principal nations of Europe despatched observers to various parts of the world for the purpose of observing the phenomenon.

The phenomenon to be observed may be readily understood by reference to Figure 9. The large circle represents the Sun. The smaller circle represents the planet. The planet enters upon the

Sun's disc, making exterior contact with it at 1, and interior contact at 2. It

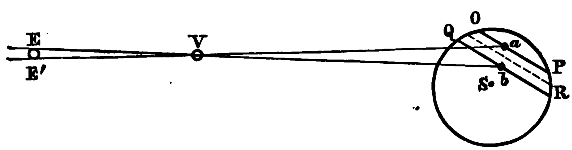
Fig. 9.



then travels along and leaves the solar disc on the right, making interior contact with the solar limb at 5, and exterior contact at 6. The object of the observer is especially to note the precise instant when the planet makes interior contact with the Sun's limb as at 2 and 5.

Two methods of determining the solar parallax, on the basis of observations of the transit of Venus over the Sun's disc, have been devised by astronomers. The

Fig. 10.

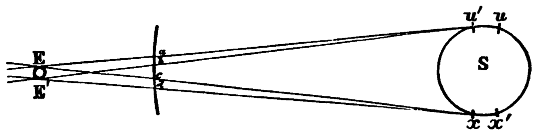


earliest of these methods was that proposed by Halley. It may be thus explained:—Let E, E′ be two places of observation in opposite parts of the Earth, the one being near the north pole, and the other near the south pole. An observer at the centre of the Earth would see the planet travel along the dotted chord included between the chords OP, QR. The observer at E sees the planet describe upon the Sun's disc the chord QR. The observer at E′ sees the planet describe the chord OP. Now, the difference between the times of describing the two chords QR, OP, constitutes an indication of the displacement in the path of the planet resulting from the difference in position between the two stations of observation E, E′. But this displacement depends upon the absolute distance of Venus and the Earth from the Sun. By means, therefore, of the duration of the transit of Venus as observed from two distant stations on the Earth's surface, an indication is obtained of the value of the solar parallax, and consequently of the Sun's distance from the Earth.

The other method of determining the solar parallax by observations of the transit of Venus, is founded upon observing the internal contact of the planet with the sun at two distant stations on the Earth's surface. Thus, let E, E′, be two such stations; the observer at E sees the ingress of the planet upon the Sun's disc when it arrives at a; on the other hand, the observer at E′ does not see the ingress of the planet until it arrives at *b*.

The interval of time which the planet

Fig. 11.



thus occupies in passing from *a* to *b* constitutes the groundwork of the solution of the problem for finding by this method the Sun's distance from the Earth.

The problem may be solved in a similar way by observations made, at two distant stations, of the *egress* of the planet from the Sun's disc. In this case the interval of time, which the planet occupies in describing the arc *c d*, as observed at EE′, supplies an indication of the Sun's distance from the Earth. This is termed Delisle's method, because it was first suggested by Delisle, a French astronomer, in contradistinction to the method based upon the observed duration of the planet on the Sun's disc, which is due to Halley.

The method of Delisle requires a comparison of the exact times of ingress or egress of the planet, as observed at the two stations. To effect this object we must determine the longitudes of the stations relatively to Greenwich or some known meridian. This is in all cases an operation of much delicacy.

Careful preparations were made to observe the transit of Venus, which occurred in 1761; but the weather was generally unfavourable for the purpose. Still more systematic and extensive arrangements were made to observe the transit of 1769. In this instance the operations were successful, the phenomenon having been satisfactorily observed by a great number of persons in different parts of the world. In 1824, the totality of the observations of the transits of 1761 and 1769 were submitted to a profound discussion by the celebrated German astronomer, Encke, who deduced from them a parallax indicating the Sun's distance from the Earth to be, in round numbers, ninety-five millions of miles. This result was speedily adopted by astronomers, and continued to be inserted in all text-books on astronomy until quite a recent period. It is now ascertained beyond all doubt that the value of the solar parallax assigned by the German astronomer is considerably erroneous.

If the planet Venus revolved in the plane of the ecliptic, it would be seen as a round spot passing over the Sun's disc every time it arrived in inferior conjunction. But, in point of fact, the orbit of the planet is inclined to the plane of the Earth's orbit, and the result consequently is that the planet can be seen on the Sun only when, at the time of inferior conjunction, it is passing through, or very near, either of the nodes of its orbit. Let us suppose two hoops, one of which is a little larger than the other. Let them both have a common centre, and let them be inclined to each other at a given angle. Further, while the Sun is supposed to be in the common centre of the hoops, let us assume that Venus revolves in the inner, and the Earth in the outer, hoop. Let a common diameter of the two hoops be drawn through the points where the inner hoop intersects the plane of the outer hoop. The points here referred to represent the nodes of the planet's orbit, and the diametral line passing through them is called the line of nodes. A transit of the planet can happen only in June or December, because the Earth can only then be situated in the line of nodes of the planet's orbit. When the planet is passing through its ascending node, the transit happens in December; when it is passing through the descending node, the transit necessarily occurs in June.

Transits generally occur at intervals of $105\frac{1}{2}$ years, 8 years, $121\frac{1}{2}$ years, 8 years, $105\frac{1}{2}$ years, 8 years, &c. Frequently, however, instead of the transits occurring in pairs, there may be only one transit and then a long interval of more than a hundred years. The recurrence of transits at intervals of only eight years arises from the fact that thirteen revolutions of the planet are effected in almost exactly the same time as eight revolutions of the Earth; consequently, if the planet should be in either of the nodes of its orbit at the time of inferior conjunction, it will be very nearly in the node after the lapse of eight years, sufficiently near, perhaps, to bring about another transi of the planet. If the planet shoulc pass over the Sun's disc very near th centre, its displacement after the laps of eight years may be too great to allov of another transit.

Earlier Transits of Venus.

THE earliest prediction of a transit o Venus over the Sun's disc is due t Kepler. In 1629 he announced tha a transit of the planet would occu in 1631. When the time assigne for the occurrence of the phenomeno finally arrived, astronomers searched fo the planet on the Sun's disc, but withou success. It is now known that the transit really did occur, but that the planet passed over the Sun's disc in the night time, and was consequently invisible to the astronomers of Europe. Another transit of Venus occurred in 1639. The phenomenon appears to have wholly escaped the attention of astronomers on this occasion, with the exception of two young Englishmen, Jeremiah Horrocks and William Crabtree, who alone had the privilege of witnessing a spectacle, the like of which no mortal had hitherto ever seen. Horrocks was curate of Hoole, near Preston. He was endowed with an original genius of a high order, and an ardent enthusiasm in the pursuit of science; and although he died in the very flower of his age, he has left behind him a name which will live imperishably in the annals of science. By means of his own calculations he discovered to his great delight that there would be a transit of the planet in November 24 (O.S.), 1639, and he hastened to make suitable preparations for observing the phenomenon.

The plan of observation devised by him consisted in admitting the Sun's light into a dark room through an aperture in the window, and receiving the image of the Sun upon a white screen attached to the opposite wall. The transit of the planet over the Sun's disc would then be indicated by the presence of a round black spot traversing the white circle.

Horrocks watched the solar image carefully throughout the whole of the 23rd of November, but no trace of the planet was seen. On the morning of the 24th, which was Sunday, he similarly scrutinized the image of the solar disc, but failed to obtain any indication of the presence of the planet. After an absence of some time, caused by the necessity of attending to his clerical duties, he repaired again with eager anxiety to the darkened chamber, when, "Oh, most gratifying spectacle!" said he, "the object of so many earnest wishes, I perceived a new spot of unusual magnitude, and of a perfectly round form, that had just wholly entered upon the left limb of the Sun, so that the margin of the Sun and the spot coincided with each other, forming the angle of contact." Owing to the near approach of sunset, Horrocks was unable to observe the planet longer than half an hour. Crabtree, who resided near Manchester, had, in accordance with instructions from Horrocks, made similar preparations for observing the phenomenon, and he also enjoyed the gratification of seeing the planet on the Sun's disc; but a cloud came over the Sun's face, and he was unable to make any precise measures. The observations of Horrocks have furnished valuable materials in recent years for correcting the elements of the orbit of the planet.

Horrocks, as already stated, died young, but he has left behind him unmistakeable proofs of a thoroughly original genius, and a capacity for the cultivation of physical science which have earned for him a lasting reputation. In the present day, when a transit of the planet is close at hand, steps have been taken by the men of science of his country to erect a fitting tribute to his memory in Westminster Abbey.

The Transits of 1761 *and* 1769.

It has been already stated that the weather was generally unfavourable for the observation of the transit of 1761. The preparations for observing the transit of 1769 were upon a more extensive scale, and led to a more successful issue. The British Government despatched observers to Otaheite, in the Pacific Ocean, for the purpose of observing the phenomenon. The ship in which they sailed, the "Endeavour," was commanded by the celebrated navigator, Captain James Cook. The other principal nations of Europe made similar preparations, with a view to the observation of the transit. The weather on the whole was favourable for the observation of the phenomenon, and the operations were skilfully executed. The method chiefly relied upon was that of durations, as illustrated in Fig. 10. Two of the most important stations were Otaheite, in the southern hemisphere, and Wardhus, in Lapland, in the northern. The duration of the transit at Wardhus was 5 hours 54 minutes; the duration at Otaheite was 5 hours 32 minutes. The difference of durations amounted therefore to 22 minutes. This interval of 22 minutes constituted the result leading to the determination of the solar parallax. If the absolute distances of the Sun and the planet from the Earth were gradually increased (the *relative* distances of the two bodies remaining unchanged), the difference of duration of the transit would gradually diminish, until ultimately it would be so small as to be inappreciable. Now 22 minutes constitute a considerable interval of time for measurement, and it happens that a small error committed in its determination would entail a relatively much smaller error in the computation of the solar parallax.

Shortly after the occurrence of the transits of 1761 and 1769 various evaluations of the solar parallax were deduced from the resulting observations, but the discordances of the results thus obtained were greater than was deemed satisfactory. It has been already mentioned that Encke submitted the totality of the observations of both transits to a comprehensive discussion. The German astronomer obtained 8″·5776 for the definitive value of the solar parallax. This would indicate the Sun's distance from the Earth to be, in round numbers, ninety-five millions of miles.

A difficulty of an unexpected and

serious nature occurred to the observers of the transit of Venus on these occasions. It was found that the ingress of the planet on the Sun's disc was characterized by the presence of a pear-shaped, dark ligament, connecting the planet with the Sun's limb, and rendering it a matter of exceeding difficulty to pronounce upon the precise instant when the two bodies formed internal contact. It was to the uncertainty of the observations arising from this cause (a purely optical one) that the discordance between the results obtained for the value of the solar parallax by different astronomers was in a great measure attributable.

More Recent Determinations of the Value of the Solar Parallax.

THE value of the Sun's distance from the Earth resulting from the researches of Encke in 1824 continued to be adopted in all popular treatises on astronomy as representing the most trustworthy value of that element which had hitherto been arrived at. In recent years, however, astronomers have found reason to suspect that the evaluation of Encke is considerably in error. As early as 1854, Hansen, in a letter to the Astronomer Royal, announced that his researches in the lunar theory seemed to indicate that Encke's value of the solar parallax was too small (and consequently that the resulting distance of the Sun from the Earth was too great). Subsequently, he determined in this manner the value of the solar parallax, and he found it to be 8″·916. Stone, the first Assistant at the Royal Observatory, Greenwich (now Her Majesty's Astronomer at the Cape of Good Hope), deduced a similar result from observations of the planet Mars, made in 1862, when it approached very near to the Earth. His computations gave 8″·943 for the resulting value of the solar parallax. About the same time Le Verrier, the eminent French Astronomer, obtained 8″·859 from his researches in the planetary theory. These various determinations concurred in indicating that the true distance of the Sun from the Earth was not ninety-five millions of miles, as had been hitherto supposed, but rather somewhere about ninety-one and a half millions of miles, or about $\frac{1}{30}$th less than the assumed value. This conclusion received a striking confirmation from an unexpected source. The velocity of light may be determined astronomically in two different ways. One of these is founded upon observations of the eclipses of Jupiter's satellites. When the Earth is in the part of its orbit which is nearest to the planet, the eclipses occur *earlier* than the predicted times. On the other hand, when it is in the more remote part of its orbit, the eclipses occur *later* than the times computed from theory. These discordances may all be got rid of by assuming that light is not propagated instantaneously, but, on the contrary, occupies some time in passing through space. Now, it is found in this way that light occupies sixteen minutes in traversing a diameter of the Earth's orbit. Assuming, then, that the radius of the Earth's orbit is ninety-five millions of miles, we hence arrive at the conclusion that light traverses space with the amazing velocity of one hundred and ninety-two thousand miles in a second.

The other method is founded upon a curious phenomenon of the stars. When their apparent positions are carefully scrutinized, it is observed that the stars all describe a very small ellipse in the heavens, a fact which may be satisfactorily explained by assuming that light occupies a certain interval of time in passing from a star to the earth. Now, the magnitude of the major axis of the ellipse described by a star in this case depends upon the proportion which the orbital velocity of the earth bears to the velocity of light. Here, then, we have three quantities, from any two of which we can derive the third—namely, the major axis of the ellipse of aberration as it is called, the velocity of the Earth in its orbit, and the velocity of light. Now, observations of the stars give us the value of the first of these three quantities, and if we assume the radius of the Earth's orbit to be ninety-five millions of miles, we can readily compute from it the orbital velocity of the Earth. Knowing then these two quantities, we are in a position to determine the third, and thus we arrive at the conclusion that light travels through space at the rate of one hundred and ninety-two thousand miles in a second, as indicated by the eclipses of Jupiter's satellites.

But, wonderful to relate, the velocity of light has been determined by an experimental process, conducted upon the Earth's surface within the compass of a few hundred yards. This has been accomplished by two distinct methods, both due to two French physicists, Fizeau and Foucault. The results obtained in the two instances agree in assigning to light a velocity of one hundred and eighty-five thousand miles in a second. Here, then, we have presented to us a striking discordance between the value of the velocity of light deduced astronomically, as stated above, and the value obtained by the French physicists. But in computing the velocity of light astronomically, we assumed that the radius of the Earth's orbit was ninety-five millions of miles. Let us, however, suppose the radius of the orbit to be ninety-one and a half millions of miles, as pointed out by the recent researches of astronomers, and we obtain by both astronomical methods a velocity amounting to one hundred and eighty-five thousand miles in a second, precisely the same value as that indicated by the experiments of the French physicists.

Thus it appears that the terrestrial experiments for ascertaining the velocity of light concurred with recent astronomical researches in indicating the necessity of adopting a larger value of the solar parallax than the value hitherto employed by astronomers.

Finally, Stone having investigated anew the question, in so far as concerned the transit of 1769, ascertained that, by a juster interpretation of some of the observations the resulting value of the solar parallax agreed very nearly with the value derived from other sources. In fact, he found in this manner the value of the solar parallax to be 8″·91, indicating the Sun's distance from the Earth to be ninety-one million six hundred thousand miles.

Details respecting the Transit of Venus in December 8, 1874.

It has been already stated that the observation of the transit of Venus consists in noting the precise instant when the planet, in its passage over the Sun's disc, forms internal contact with the margin of the Sun, first at its ingress upon the solar disc, and secondly, at its egress from the disc. If we suppose an observer to be situated at the centre of the Earth, he would see the internal contact at ingress on the morning of the 9th of December at 2 h. 15 m. Greenwich Mean Time, and he would see the internal contact at egress at 5 h. 57 m. The included interval of time is therefore 3 hours 42 minutes. But the interval of time which elapses between the instant when the planet first impinges on the solar disc, and the instant when it finally leaves the disc is necessarily somewhat greater, as may be seen by referring to Fig. 9. It amounts, in fact, to 4 hours 41 minutes. An observer on the Earth's surface, having the Sun in his zenith, would see the different phases of the transit exactly as an observer at the centre of the

Earth would see them. But the result would be different if he were stationed at any other place on the Earth's surface, as may be readily understood by referring to Figures 10 and 11. Let us confine our attention to the instant of internal contact at ingress and egress. Of course, the transit can only be visible from the illuminated hemisphere of the Earth; or, in other words, the hemisphere which is turned towards the Sun. Now, there are certain places on the Earth's surface from which the internal contact of the planet with the Sun at ingress may be seen *earlier* than it would be seen to an observer stationed at the centre of the Earth; and again, there are other places where the internal contact at ingress would be seen *later* than it would be seen from the centre of the Earth. Now, if the Sun had no sensible parallax, the time of internal contact, whether at ingress or egress, would be the same everywhere on the Earth's surface as at the centre. It is clear, then, that the difference between the times of internal contact at ingress or egress, as observed from two distant stations on the Earth's surface constitutes the *datum* available to the astronomer for the solution of the problem of the Sun's distance from the Earth. The following plan of localization as regards stations accordingly offers itself as most suitable for observing the phenomenon.

1. Stations where the internal contact at ingress is accelerated.

2. Stations where the internal contact at ingress is retarded.

3. Stations where the internal contact at egress is accelerated.

4. Stations where the internal contact at egress is retarded.

It is upon this principle that astronomers have selected a great number of stations in various parts of the world, for the purpose of observing the transit. Let us take, for example, Woahoo in the

Sandwich Isles, and Kerguelen Island. The internal contact will be seen eleven minutes *earlier* from Woahoo, and twelve minutes *later* from Kerguelen Island than if it were viewed from the Earth's centre. Hence the interval between the times of internal contact, as seen at Woahoo and Kerguelen Island, amounts to twenty-three minutes. Similarly, the astronomer combines the observations made at two stations, where the internal contact at *egress* is seen *earlier* in the one case, and *later* in the other, than if the phenomenon was seen at the centre of the Earth.

Arrangements for observing the Transit of Venus in 1874.

As early as 1857, the Astronomer Royal, in a paper communicated to the Royal Astronomical Society, drew the attention of astronomers to the approaching transits of Venus over the Sun's disc in 1874 and 1882; and on several subsequent occasions he explained his views on the subject to the Society. The Government having been made to understand the importance attached to the proper observation of the transit of 1874, induced Parliament to vote a considerable sum of money for defraying the necessary expenses. The whole of the arrangements connected with the different expeditions for observing the phenomenon have been planned and executed under the superintendence of Sir George Airy, the Astronomer Royal. Five stations were originally chosen for the observation of the transit. These were, Alexandria, Honolulu, Rodriguez, New Zealand, and Kerguelen Island. It was subsequently considered desirable to supplement the station at Honolulu by two additional stations at some distance apart. These are Hawaii and Kauai. An additional station has also been attached to Kerguelen Island,

and one at Cairo, in connection with the station at Alexandria. Furthermore, two stations have been established in India. In addition to these preparations, the transit will not fail to receive due attention at the observatories of Melbourne, Sydney, the Cape of Good Hope, and Madras. Some of the Colonial Governments of Australia have voted special grants of money for the observation of the phenomenon. Then there is the very complete expedition fitted out by Lord Lindsay, with the view of observing the transit at the Mauritius. Colonel Campbell, of Blythswood, has also undertaken to observe the phenomenon at Thebes. The various observing parties despatched from Greenwich have been furnished with an admirable equipment of instruments with the use of which the several observers have undergone a course of training at the Royal Observatory during the last two or three years, under the guidance of Captain Tupman, R.M.A. Photography will be used in connection with the observatories at all the stations. Mr. Warren De La Rue has liberally undertaken to superintend this part of the Greenwich arrangements. Much ability has been displayed by Proctor in the discussions generally relating to the two transits.

The observers connected with the various Greenwich expeditions are chiefly naval officers, with the addition of some officers of the engineers and artillery, and a few private observers. The following plan of arrangements, relative to the appointment of the different observers, was drawn up and issued some months ago by the Astronomer Royal.

Appointments of Observers to the several Districts of Observation, and Subordination of Observers.

"1. Captain G. L. Tupman, R.M.A., is head of the entire enterprise, and is responsible, through the Astronomer

Royal, to the Government for every part. Every observer is responsible to Captain Tupman.

"2. When the different expeditions are separated, the observers in each district of observation are responsible to the local chief of the district, and the chief to the Astronomer Royal. The districts of observation and the observers will be the following, the name first following that of the local chief being that of the deputy, who will, if necessary, take his place;—

"3. District A. Egypt: Chief, Capt. C. O. Browne, R.A., astronomer; Observers, Capt. W. de W. Abney, R.E., astronomer and photographer; S. Hunter, astronomer.

"4. District B. Sandwich Islands: General Chief, Capt. G. L. Tupman, R.M.A.: Deputy, if necessary, Prof. G. Forbes.

"Subdivisions of the Sandwich Islands:—Honolulu: Chief, Capt. G. L. Tupman, astronomer; Observers, J. W. Nichol, astronomer and photographer; Lieut. F. E. Ramsden, R.N., astronomer and photographer. Hawaii: Chief, Prof. G. Forbes, astronomer; Observer, H. G. Barnacle, astronomer. Kauai: Chief, R. Johnson, astronomer; Observer, Lieut. E. J. W. Noble, R.E.M., astronomer.

"5. District C. Rodriguez: Chief, Lieut. C. B. Neate, R.N., astronomer; Observers, C. E. Burton, astronomer and photographer; Lieut. R. Hoggan, R.N., astronomer and photographer.

" 6. District D. Christchurch (New Zealand): Chief, Major H. Palmer, R.E.; Observers, Lieut. L. Darwin, R.E., astronomer and photographer; Lieut. H. Crawford, R.N., astronomer.

" 7. District E. Kerguelen Island: General Chief, Rev. S. J. Perry; Deputy, if necessary, Lieut. C. Corbet, R.N.

" Sub-divisions of the Kerguelen Island:—Christmas Harbour: Chief, Rev. S. J. Perry, astronomer and photographer; Observers, Revs. W. Sidgreaves, astronomer; Lieut. S. Goodridge, R.N., astronomer; J. B. Smith, astronomer and photographer. Port Paliser: Chief, Lieut. C. Corbet, R.N.; Observer, Lieut. G. E. Coke, R.N.

"8. In addition to these gentlemen, three non-commissioned officers or privates of the Corps of Royal Engineers will be attached to each of the five districts, and will be under the direction of the chief of each district."

Expeditions for observing the transit have also been sent to various parts of the world by the Governments of France, Germany, Italy, Holland, Russia, and the United States of America.

Concluding Remarks.

IT has been stated that the solar parallax, as generally adopted by astronomers in the present day, would place the Sun at a distance of ninety-one and a half millions of miles from the Earth. This element puts us at once in possession of the distances of all the planets from the Sun. In this manner we arrive at a knowledge of the dimensions of the system of which the Earth forms one of the constituent bodies. We find the extreme planet of the system revolving round the Sun to be situated at a distance of nearly three thousand millions of miles. We discover that the planets are bodies of immense size, several of them vastly exceeding the Earth in magnitude. We obtain from the same source a knowledge of the magnitude of the orbits of the satellites which are found to accompany the larger planets of the system. Once in possession of a knowledge of the solar parallax, we are enabled to determine the masses of the planets by comparing them with the sun's mass. The same important element gives us information respecting the amazing velocity with which the planets travel in their orbits, and the consequent enormous intensity of the sun's attraction, which prevents them from flying off into space. If we direct our attention to the system of comets, we are equally struck with the light thrown upon the movements of those mysterious bodies by our knowledge of the solar parallax. We obtain an instructive insight into the amazing velocity with which in many instances they travel in their orbits, we measure the dimensions of their orbits, and compute with precision the distances to which, when travelling to their aphelia, they recede into the illimitable depths of space. The planet Neptune revolves round the sun at a distance of nearly *three thousand millions of miles* from the Earth. The great comet of 1858, when passing through the aphelion of its orbit, recedes to a distance of *thirty thousand millions of miles* from the Earth, and yet this enormous distance amounts to *only a seven hundredth part* of the distance of the nearest of the fixed stars. It is to be remembered furthermore, that whatever knowledge we possess respecting the distances, magnitudes, and masses of the fixed stars, is dependent on the same element. As soon as we have determined the radius of the Earth's annual orbit round the Sun, we can make use of the diameter as a new base-line, and upon this immensely improved vantage ground proceed to determine the distances of the stars. When Copernicus propounded the true system of the universe, it was argued by his opponents that according to his views the stars ought to present an annual variation of aspect and position depending upon the motion of the Earth in its orbit. Copernicus met this objection by remarking that the whole solar system was a mere point in comparison with the sphere of the fixed stars. It is worthy of note, that until a comparatively recent period, this was the only reply which could be given to the opponents of the Copernican theory. In the present day several stars have been detected, presenting parallaxes of such undoubted magnitude, that we are enabled with perfect confidence, to assign their distances from the Earth. The results which have been arrived at by researches in this branch of astronomy, are calculated to inspire with awe all who devote their attention to the subject. Even the masses of the stars have been, in some instances, determined; and we arrive in this manner at the startling conclusion that the luminaries of the stellar vault are bodies of immense size, rivalling the Sun in magnitude and splendour. It has been an opinion generally held by astronomers, that the stars are distant Suns. Our knowledge of the value of the solar parallax, combined with the results of recent researches in stellar astronomy, assure us beyond all doubt of the reality of this fact.

We shall conclude with a statement of the steps by which the human mind is enabled to ascend in succession to the contemplation of these lofty truths. First, the astronomer measures a base line seven or eight miles in length upon the Earth's surface. Combining this result with the solar parallax, he determines the distances of the planets from the sun, their magnitudes and masses, and the velocities of their orbital movements. He computes the dimensions of the orbits of comets and meteor streams, and assigns with precision the distances to which they recede into space when they have reached the aphelia of their orbits. Finally, assuming as a new base line for his researches the diameter of the Earth's orbit, a line measuring a little more than a hundred and eighty millions of miles in length, he determines the distances and masses of the stars. He computes the velocities with which they travel in space, and compares them in this respect with the movement of the solar system in space. Nay, the spectroscope informs him respecting the materials of which those remote bodies consist, and thus teaches him another important fact in support of the grand doctrine that the Sun is no other than a star, and that the innumerable bodies of the stellar vault are magnificent globes of light, rivalling the Sun in magnitude and splendour. We have here presented to us a striking instance of the sublimity of the views respecting the immensity of the physical universe which the science of astronomy has disclosed to the researches of the human mind.

GLASGOW:
PRINTED AT THE UNIVERSITY PRESS.