## THE COMING TRANSIT OF VENUS*

### III.

IN the previous articles various methods have been indicated by means of which we may discover the scale upon which the plan of the solar system is drawn. The last article concluded by illustrating the nature of the methods of employing a transit of Venus, as proposed by Halley. It will be noticed that this method can be utilised in the way there indicated only when Venus passes nearly across the diameter of the sun. Halley, in fact, founding his calculations upon erroneous data, was led to conclude that this would be the case in 1761. In this he erred, and another slight but important mistake having been made in his calculations, it followed that at Hudson's Bay, his northern station, the transit was invisible.

The present article will be devoted to a description of the methods to be employed in the coming transit for determining the solar parallax. In subsequent articles the preparations which have actually been made for observing the transit of 1874 will be described; and the difficulties encountered in this kind of observation enumerated.

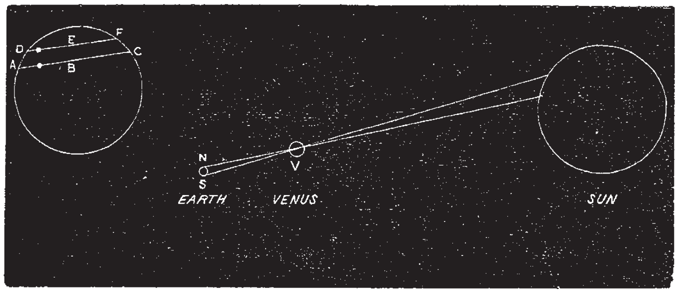


FIG. 11.

Let the reader now examine Fig. 11 and pay particular attention to the description of it, and he will thus be enabled better to understand what follows. The earth, Venus, and the sun are here represented in their relative positions; and lines are drawn to show the directions in which two observers at opposite sides of the earth will see Venus upon the solar disc. It follows from this that an observer on the southern portion of the earth will see Venus trace a path D E F upon the sun's disc farther north than the path A B C which a northern observer on the earth sees it trace. Now Venus will be three times as far from the sun as from the earth on that date. From this it follows that the distance between the two lines A B C and D E F will be three times as great as the distance N S. But the distance N S upon the earth can be

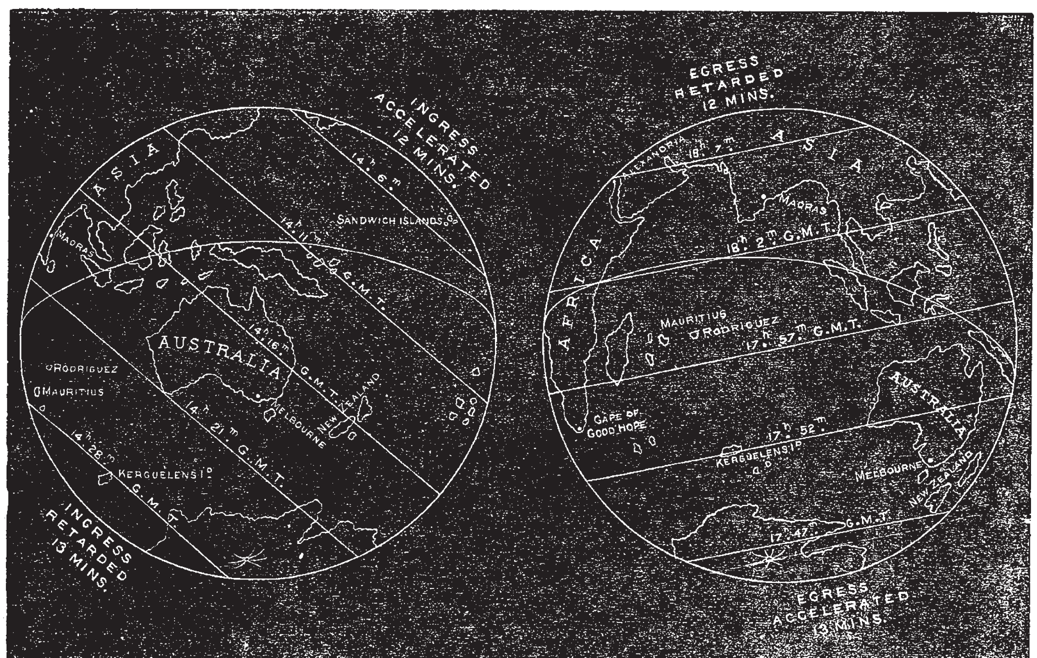


FIG. 12.

easily found out. Suppose it to be 6,000 miles. In that case the distance between A B C and D E F is known to be 18,000 miles. But it needs no demonstration to convince us that if we have a distance of 18,000 miles measured out for us upon the sun's surface we can determine the distance of the sun from the earth.

Now the apparent distance between the two lines A B C and D E F is the least observed distances between Venus' centre and the sun's during the transit. *If then, we can measure accurately the least distance between the centres of Venus and the sun, at two stations suitably chosen, we can determine the sun's distance.*

There are three methods by means of which this may

* Continued from vol. ix. p. 489

be effected; the photographic method, the heliometric method, and the method of durations. We shall consider these in order.

I. *The Photographic Method.*—It is easy to see that by continuing during the transit to take photographs of the sun, in which Venus will be represented as a black spot, these photographs may be so combined as to indicate definitely the apparent path of Venus as seen at these two stations. This method is looked forward to with much interest, because it is the first time that photography has been extensively employed in delicate astronomical measurements. It is not generally known how extremely accurate a means of observation photography is. We owe much to Mr. De la Rue, whose success in the application of photography to astronomy has been unequalled, for having given us a most clear account of what has been done in this way.* The method has been employed in America to measure the distances between double stars. The double star is photographed and the distance is afterwards measured as accurately as possible. Prof. Bond finds that the probable error of such a measurement is 0''·072 or $\frac{1}{3}$ of the probable error of a similar measure made with a filar micrometer as estimated by Struve. Photographic pictures of the sun were for many years daily taken at Kew, and it was found that an extremely accurate measure of the sun's diameter could thus be made. If the lens of a common telescope were used to produce an image of the sun upon the sensitive plate the picture would be too small for accurate measurement. Hence a special instrument called a photoheliograph must be devised to give an enlarged picture upon the sensitive plate. Two perfectly distinct kinds of instruments are to be used for this purpose, the one English, the other American. Mr. Dallmeyer has, under the superintendence of Mr. De la Rue, constructed photoheliographs for the English and Russian expeditions. In these instruments the image of the sun produced in the focus of an ordinary telescope is enlarged by a special arrangement so as to give a picture of the sun about four inches in diameter. This instrument, based upon the principle of the Kew photoheliograph, is very perfect in its results and convenient in actual practice. It is mounted equatorially so as to follow the motion of the sun. The sensitive plate, which is prepared in an adjoining room, can be readily inserted and exposed. The intensity of direct solar light is so great that special means are necessary to give a short enough exposure. Before a photograph is taken a sliding shutter in the interior of the instrument cuts off all light from the sensitive plate. This shutter is held in its place by a cotton thread. So soon as this thread is cut, a strong spring draws down the shutter, in which is a slit about $\frac{1}{40}$th of an inch wide. The time taken by this slit to pass over any part of the sun's image is the whole interval required for an exposure.

The other method of obtaining a large picture of the sun is by employing a lens of great focal length. This method was originally proposed by Mr. Rutherford, of New York, and will be employed by the Americans, and also by Lord Lindsay in his observations at the Mauritius. The focal length of the lens is forty feet. But a telescope of such dimensions could not be conveniently mounted in the ordinary way. To overcome this, a siderostat similar to the one originally constructed by M. Foucault for the Observatory of Paris is employed. This instrument consists of a plane mirror so mounted as to send the sun's rays always in the same horizontal direction. In the path of these rays, and close to the siderostat the lens is placed, and at a distance of forty feet an image of the sun about four inches in diameter is produced. At this place a window is arranged in the photographer's hut, and by means of this arrangement the photographer need never leave his dark room. After preparing a plate he places it in position at the window; when exposure has been made he may remove the plate and develop it.

Considerable advantage is likely to accrue to the employment of dry plates, which will diminish the labour of the photographer. Researches upon this matter have been undertaken by Prof. Vögel, in Holstein, Col. Smysloff, at Wilna, and by Capt. Abney, at Chatham. The employment of a dry process prevents all danger from the shrinking of the collodion-film. Herr Paschen* and Mr. De la Rue have made experiments upon this point. The latter gentleman finds that all shrinkages take place in the thickness of the film, so that the measurements would not be affected by it. But the more convenient dry-plate process is undoubtedly safer. Judging from the data furnished by Mr. De la Rue, this photographic method will give results of the utmost value.

II. *The Heliometric Method.*—The exact measurement of the distances of the edges of Venus from opposite edges of the sun would enable us easily to determine what is required, viz., the least distance between the centres of the sun and planet. But the ordinary astronomical means are useless in measurements of this magnitude. To obviate this, a special instrument, called a heliometer, will be employed by the Germans and Russians, and by Lord Lindsay. This instrument was originally invented for measuring the diameter of the sun. The object-glass of a common telescope is divided so as to form two semicircles. A screw adjustment allows us to slip one-half of the lens past the other one along their line of junction; a fine scale measures this displacement. When the two halves of this object-glass are relatively displaced, two images of the sun are seen overlapping. The distance between the two images is proportional to the relative displacement of the two halves of the object-glass. This instrument has been brought to a state of great perfection by Mr. Repshold, of Hamburg. It is a very troublesome instrument to manipulate, and the corrections due to the influence of temperature are extremely difficult to apply. Yet with great care there is little doubt that very accurate measurements can be made. The nature of the measurements required to obtain the distance between the centres of Venus and the sun will readily be understood. The method has been most ably discussed by Lord Lindsay and Mr. Gill in the Monthly Notices of the R.A.S., November 1872. At the same time it is difficult to conceive that this direct method will give results of equal value with the methods hereafter described. In fact, an opposition of Mars would be expected to give equally good results; for the distance of Mars from a fixed star can be more accurately observed with a micrometer than the distance between the centres of Venus and the sun; and a larger number of observations could be made.

III. *The Method of Duration.*—The third method of determining the least distance between the centres of the sun and Venus is less direct than either of the preceding methods; but it has stood the test of a previous trial, and we cannot say but that it will be more satisfactory than the other methods in the coming transit. The method of duration closely resembles the method originally proposed by Halley. The duration of the transit, as viewed from two distinct stations, is accurately determined. But the difference in this duration is affected by choosing stations upon a different system. Nevertheless this method is frequently called Halley's method. His method consisted in choosing two stations, so that during the transit the one should be moving eastward and the other westward. It is further essential for success that Venus should pass nearly along the diameter of the sun. In the method employed last century, the two stations were chosen—the one far north, and the other far south. On referring to Fig. 11 it will be seen that in each case Venus appears to pass along a chord of the sun. But in

* Address to the Mathematical and Physical Section of the British Association, Brighton, 1872.

* *Astronomische Nachrichten*, 1872, lxxix. 161.

the one case this chord is farther from the sun's centre, and consequently shorter than the other. The duration of the transit, so far as this effect is concerned, is directly proportional to the length of the chord traced out by Venus. Thus from observation we obtain the lengths of these chords; and by geometry we can deduce the least distance between the centres of the sun and Venus at each of the two stations, and hence we can determine the sun's parallax. Fig. 12 illustrates this point very clearly. The duration is determined by two distinct observations made at each station, the internal contact at ingress and the internal contact at egress. The time of an internal contact is the time at which Venus appears to be just wholly within the sun's disc. These two times must be accurately determined; they will be separated by an interval of nearly four hours. Fig. 12 represents the illuminated hemispheres of the globe at the time of ingress and at the time of egress respectively in 1874. At either of these epochs the sun will be visible from every place marked on the corresponding map. The sun will be vertical at the place occupying the centre of the map; at all stations near the edges of the map the sun will at that time be near the horizon. The point from which the phenomenon will be first observed is there indicated, and likewise the point at which it is last seen. Straight lines are drawn across each map, and the hours marked upon them indicate the time at which the phenomenon will be seen.

Fig. 13, taken from Lockyer's "Popular Astronomy," shows the same facts for the transit of 1882.

Take now the case of two particular stations. At some point on the east coast of China the ingress is accelerated by 6 minutes, but at the same point the egress is retarded 7 minutes; consequently the duration of the transit is lengthened 13 minutes. Again, at Kerguelen's Island the ingress is retarded 10 minutes, while the egress is accelerated 5 minutes. Here then the duration of the transit is shortened 15 minutes. The difference in duration as observed from these two stations will therefore be about 28 minutes. These maps have no pretension to great accuracy. They are calculated upon a certain assumption as to the value of the solar parallax which is probably not far from the truth.

In 1761 considerable preparations were made for observing the transit of Venus in this manner. The English were represented by Messrs. Mason and Dixon at the

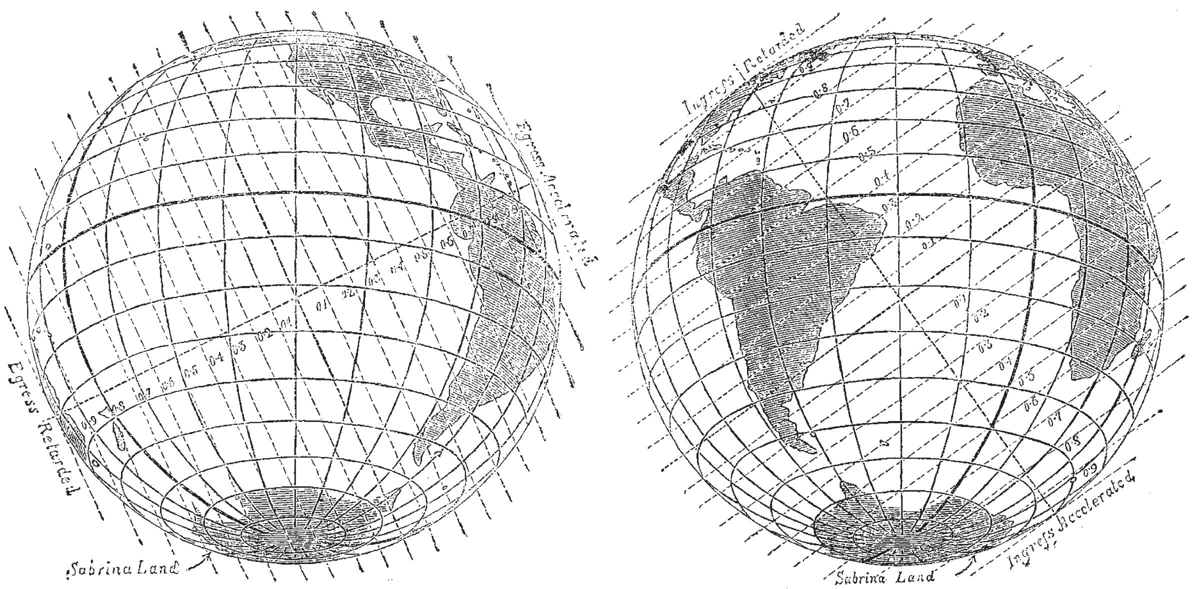


Fig. 13.

Cape of Good Hope, and the French by the celebrated Pingré at the island of Rodriguez. A host of observers watched the phenomenon from northern regions. Unfortunately at scarcely a single station was the transit seen completely. Hence the method of durations was inapplicable, and another, originally proposed by De l'Isle,* came into use. This takes advantage of the fact that the ingress will take place later when seen from some parts of the earth than from other parts, as explained above; so with the egress of the planet from the sun's disc. Hence, if the absolute time of contact of Venus with the sun's edge at ingress or at egress be observed at two places suitably chosen, the difference in time will be a measure of Venus's parallax.

The method of De l'Isle will perhaps be better understood by looking upon the orbit of Venus as a vast protractor for measuring small angles. Venus passes relatively to the earth round the sun, that is through 360° in 584 days. From this it follows that she passes over $1''\cdot5$ in one minute of time. Now conceive two straight lines to be drawn from the sun's edge, the one to the Sandwich Islands, where the ingress is most accelerated, and the other to Kerguelen's Island, where it is most retarded. Venus passes across these two lines like the radial arm of a protractor. The observed difference in the time of observing the phenomenon at these two stations will be about 21 minutes. Of this about 11 minutes is due to the fact that the Sandwich Islands are north of Kerguelen's Island, as before explained; the remaining 10 minutes or so will be a measure of the angle between the two lines drawn from the sun's edge to the two stations. Since Venus passes over $1''\cdot5$ in 1 minute, 10 minutes gives us $15''$ for the effect of parallax looked at in this light.

It is a comparatively easy matter to set one's clock accurately to local time by astronomical observations. But it is a matter of considerable difficulty for an observer in Kerguelen's Island to set his clock accurately to the local time of the Sandwich Islands, or *vice versâ*. Consequently there will be some difficulty in determining the absolute difference of time of contact as observed at these two stations. The difficulty simply consists in determining the longitude accurately. This is a matter involving a long series of astronomical observations even now; still

* Histoire de l'Acad. des Sciences, p. 112.

more so in 1761. Such observations were then wanting. Hence the application of this method was not successful, and results of that transit were unsatisfactory.

Not daunted by the comparative failure of that attempt, the astronomers of last century made vigorous efforts to make the transit of 1761 successful. The transit of 1761 was utilised in so far as it pointed out the difficulties in this kind of observation and gave them an approximate value of the sun's parallax to help them in choosing the most advantageous stations from which to observe the next transit.

Halley had no conception, when he proposed this kind of observation, of the difficulties attending it. The difficulty chiefly consists in determining accurately the exact instant when the contact seems to take place. The values which have been deduced from the observations of last century, and especially of the year 1761, have varied considerably according to the mode of reducing the observations. Thus in 1761 Lalande * found, from the observations of Pingré, 9″·4 for the solar parallax, while Maskelyne found from the work of Mason and Dixon 8″·6; Short † made it 8″·65; Wargentin, 8″·1 to 8″·3. Encke ‡ showed that the differences were partly due to an error in the longitude of Rodriguez. This question will be capable of further discussion after this year, as Rodriguez is one of the stations chosen by the English from which to observe the coming transit.

Since the observers are likely to differ considerably in the manner in which they observe the contact, and since it is difficult for us to be sure that all observers have really actually noted the same phenomenon, photography is once more brought to our aid. Some time ago M. Janssen proposed a method for determining by the aid of photography the exact instant of contact. The value of his method was immediately recognised, and steps have been taken to utilise it. The method consists essentially in exposing different parts of a prepared photographic plate in succession to the sun's light, so as to photograph that portion of the sun's limb at which the planet is visible. By the aid of no very complicated mechanism a circular plate is so arranged that sixty different portions of its surface near the circumference are successively brought into position, and exposed to the action of the sun's rays. The plate completes a revolution once in a minute, so that sixty photographs are taken at intervals of one second. A person who is observing with a telescope can easily give a signal to commence these photographic operations at the proper time. Thus one of the photographs will be sure to give us an indication of the time of true contact. Furthermore each one of the photographs taken at one station can be compared with a corresponding one taken at another station, so as to give us a means of deducing the sun's parallax. The advantages of this method are enormous. The uncertainty which exists with respect to eye observations is in a great measure due to fluctuations arising from tremors in the instruments, and variations in the density of the intervening air. In the photographic method, means have been taken to avoid these tremors as far as possible; and the instantaneous manner in which the photographs are taken will reduce these uncertainties to a minimum.

Various suggestions have been made as to the possibility of observing the exact time of the external contact by using a spectroscope in a beautiful manner originally executed by Mr. Lockyer and M. Janssen for observing the solar protuberances. Father Secchi has, in a very able memoir, pointed out a way by means of which this can be done; M. Zöllner has likewise pointed out the advantages of this method.

The observation of external contact is doubtless very useful as supplementary to the internal contact. The chief difficulty consists in the uncertainty of fixing the telescope in the proper position, so as catch the exact point of the sun's limb. This difficulty would certainly be to a large extent obviated by the employment of the ingenious adjustible ring-slit devised by Mr. Lockyer. This device has, we believe, been fully tested, with satisfactory results. It is much to be regretted that more observations to test its utility have not been made; as on this account it is not likely to be employed in the coming transit.

* Phil. Trans., vol. lii., p. 647.
† *Ibid.*, p. 648.
‡ Zach. Corresp. ii., 1819, p. 367.

We have now completed the geometrical examination of the nature of the observations on the transit of Venus, by means of which the sun's parallax will be deduced. The complete examination of the question, including analytical methods, cannot be here dwelt upon. Anyone who is interested in this should consult the valuable work "Les passages de Vénus sur le disque Solaire," by M. Edmond du Bois, lately published, in which the theoretical part of the question is very fully investigated.

RECAPITULATION.—Before leaving the technical view of the matter it will be well to recapitulate what has hitherto been stated.

1. We know the *relative dimensions* of the solar system accurately; but we do not know the *scale*.

2. The determination of the distance of the earth from the sun or from any of the planets, at a fixed date, fixes the scale.

3. This may be determined (1) by the aid of a transit of Venus; (2) by an opposition of Mars; (3) by a knowledge of the velocity of light combined with observations of eclipses of Jupiter's satellites; (4) by the velocity of light and the constant of aberration; (5) by the calculated effects of the sun's disturbance upon the lunar motions.

4. A transit of Venus may be utilised :—
   (*a*) By the determination of times of contact at different stations, combined with a knowledge of the longitudes of these stations.
   (*β*) By determining the least distance between the centres of the sun and Venus during the transit, observed from different stations.

5. This last determination may be made by either of these methods :—
   (1) The Photographic Method.
   (2) The Heliometric Method.
   (3) The Method of Durations.

GEORGE FORBES

## *NOTES*

THE Board of Trinity College, Dublin, have appointed R. Ball, LL.D., F.R.S., to be Royal Astronomer of Ireland, on the foundation of Dr. Andrews. The announcement of this appointment will be received with every satisfaction, as Dr. Ball has already, while acting as assistant to Lord Rosse, distinguished himself as a practical observer. We feel sure he will not forget to profit, or omit to allow astronomical science to profit too, by the excellently appointed observatory at his command. This vacates the chair of Applied Mathematics in the Royal College of Science, Dublin.

AT a meeting of the donors of the Yorkshire College of Science (see NATURE, vol. ix. p. 157) held at Leeds last Thursday, the constitution of the College was agreed upon, and a board of governors elected. The sum required to establish a College of Science in any way worthy of Yorkshire would be 60,000*l.*, of which only about 25,000*l.* has as yet been collected. With this sum, however, we are glad to see that it has been resolved to make a start, and we have no doubt that when the practical benefits of the institution become evident there will be little difficulty from lack of funds We trust with Lord F. Cavendish that, ere long, the institution just organised will occupy in Yorkshire a position similar to that occupied by Owens College in Lancashire. Several speakers referred to the fact that in the