THE TRANSIT OF VENUS

ITS MEANING AND USE

BY

T. H. BUDD, F.R.A.S.

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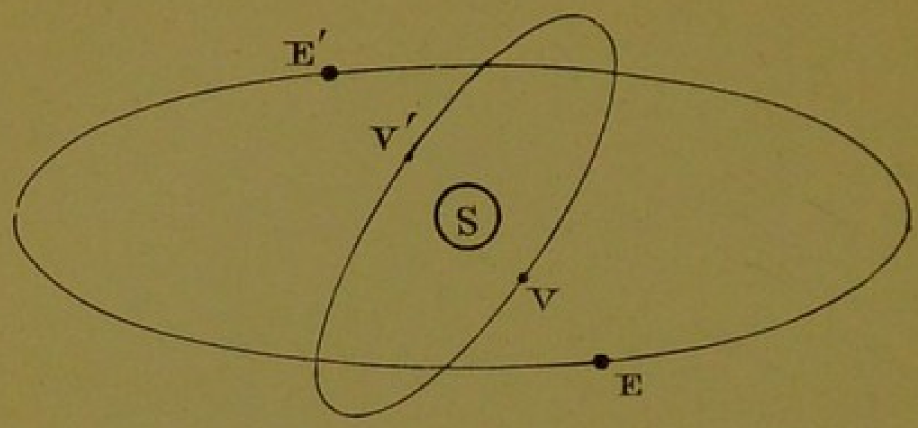
DIAGRAM No. 1.



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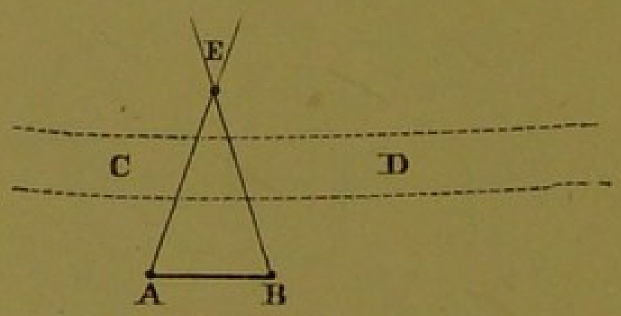
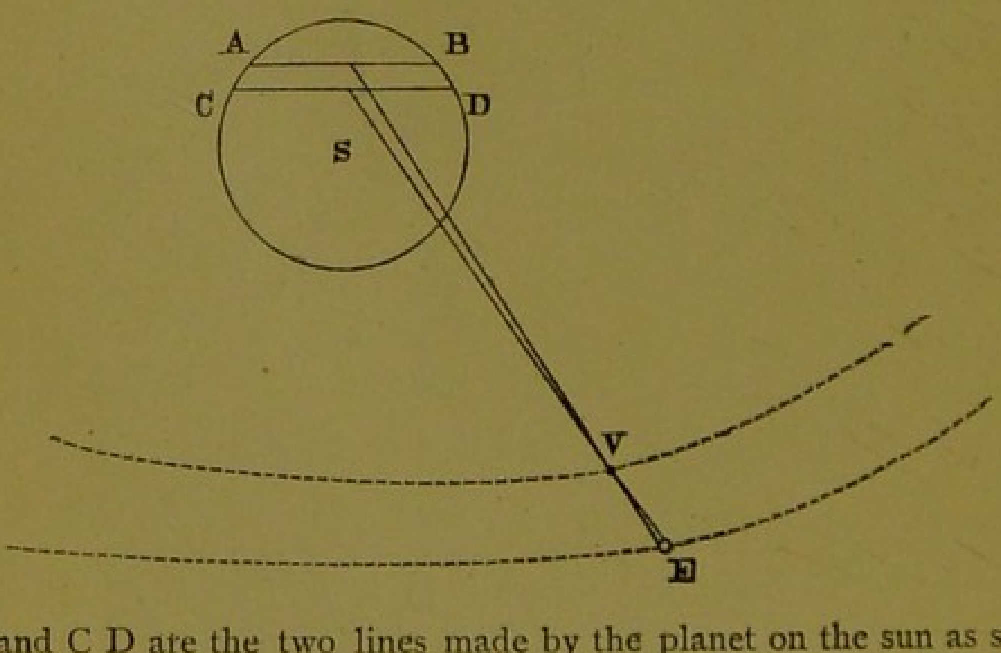


DIAGRAM No. 3.



A B and C D are the two lines made by the planet on the sun as seen from the two stations. V Venus, E the Earth.

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PREFACE.

A QUESTION was asked in *Punch* not long ago, whether any one would explain the 'Transit of Venus.' It has occurred to the writer that an explanation in simple and untechnical language might indeed instruct as well as amuse those who are sufficiently curious to think about the matter, but who, perhaps, from want of time and leisure, cannot bring themselves to face the apparently overwhelming difficulties connected with the study of Astronomy in general, which they think they must overcome before they can arrive at the meaning of the (astronomically speaking) great event that occurred in December, 1874. Let me, however, assure my readers it can be made intelligible even to those who have never looked into a book on Astronomy. A perusal of the following pages will, I hope, prove my assertion.

THE

TRANSIT OF VENUS.

SECTION I.

FIRST of all, let me explain what the transit of Venus is. It is, in fact, the passing of the planet between the Earth and the Sun in such a way as that it will be actually seen from the Earth travelling across the Sun's face. Were Venus nearer the Earth, so as to appear as large as the Moon, the planet being in fact nearly three times as large in diameter as the Moon is, her transit across the Sun would cause an eclipse of the Sun. Being very much more distant from us, however, than the Moon is, and consequently appearing very much smaller, the 'eclipse' is reduced to a 'transit,' and, instead of covering the face of the Sun, the planet appears during the transit like a small round black spot. We all know that an eclipse of the Sun is caused by the Moon passing between the Sun and the Earth, they being all three in a line. In like manner, to cause a transit, the Sun, the planet, and the Earth must be all in a line, the planet, of course, being between the Sun and the Earth.

A transit of Venus, as my readers have doubtless inferred from the fact of its causing so much stir, is a comparatively rare event. It is none the less certain and regular, however, in its periods. The transit occurs twice in about every 116 years, that is to say, it occurred last in the year 1769, having previously occurred in the year 1761. It occurs now in 1874, and it will occur again in 1882, and it will not occur again for another 108 years, and eight years afterwards it will appear again on the Sun's disc. This long interval arises from the fact, that the orbit of Venus round the Sun is *inclined* to the orbit of the Earth round the Sun, that is to say, they do not both make their circuit round the Sun in the same plane. Were they to do so, transits would be very frequent. A reference to diagram No. 1 will show what I mean by the orbit of Venus being inclined to that of the Earth. It will be seen that it is impossible for the Sun, Venus, and Earth to be in a line except when, assuming the plane of the Earth's orbit to be horizontal, Venus is ascending or descending in her orbit and so cutting through the plane of the Earth's orbit, and then, of course, only when the Earth happens to be in one of two particular positions when the plane is cut through by Venus. By calculation it is ascertained as a fact that the Earth would be in one of those positions on the 9th December, 1874, at a time when Venus would be cutting through the plane of the Earth's orbit; in other words, it is found by calculation that the Sun, Venus, and the Earth should all be in a line at a particular moment. Unfortunately for Europeans, the transit takes place before the sun rises in Europe.

SECTION II.

THE object astronomers have in view in observing the transit is that of ascertaining the distance of the Sun from the Earth. There is supposed to be an error of some three millions of miles in the present estimate of the distance, and the transit of Venus is looked forward to as a means of determining it with greater accuracy. There will probably always be some error in the calculation of the distance, and all that is hoped for is that it may be reduced to inappreciable dimensions.

The Sun is an inaccessible object, and as such of course its distance cannot be measured in the same way as an accessible object. Let us see first of all, therefore, how the distance of inaccessible objects on the Earth are measured. This will assist us considerably in comprehending the measurement of the distance of the Sun by means of the transit of Venus.

Suppose a man standing on the bank of a river wants to ascertain the distance of a particular object on the opposite bank. We will assume that he has no possible means of measuring it with a tape or chain. We will, however, suppose him in possession of an instrument which every surveyor is familiar with, viz., a theodolite.[1]

He first of all measures as accurately as he can, by means of a tape or something of that kind, and parallel to the river, a *base line*, the length of which he fixes according as the object is far off or near. If far off a large base line is chosen, if near he requires only a small one. At one end of the base line he then plants his theodolite, and looks through the telescope at some object at the end or exactly in a line with the base line, and to make the measurement as simple as he can, moves the graduated disc so that the point where it is marked 360 lies exactly on the base line; he then clamps or fixes the disc. He then turns the telescope to the object, and obtaining a view of it he refers to the disc to see how many degrees he has had to turn his telescope, and having ascertained them and noted them down, he then takes his theodolite to the other end of the base line and goes through a precisely similar process, only on this occasion he looks first towards the end of the base line where he began. In this case also he notes the number of

[1] A theodolite is an instrument used to determine the size of angles. It consists, in fact, of a small telescope fixed on a pivot, round which it can move horizontally. The pivot is fixed in the centre of a circular disc, which disc is also placed horizontally. The rim of the disc is marked in degrees, that is to say, it is divided into 360 equal parts, and a point or needle corresponding with the telescope travels with the telescope over this rim like the hand of a watch. The whole apparatus when in use stands upon three moveable legs.

degrees he has to turn his telescope. He then takes a scale and draws on paper a base line to the length of his original base line *according to the scale*; he then, by means of a circular or semi-circular scale with degrees marked on it in the same way as the theodolite disc, and referring to his notes with respect to the angles measured by the theodolite, marks them on the paper; he then draws a line from each end of the base line through the points he has fixed with his circular scale. These two lines will necessarily meet at some point or other, and thereby a triangle is formed. At the point where the two lines meet, the inaccessible object is fixed on paper. He has now nothing more to do than to measure the respective lengths of these two lines, and he will see what proportion they bear to the base line, and knowing the exact length of the base line he is enabled to measure the exact length of each of his two meeting lines. To make this explanation more apparent, the reader can compare it with diagram No. 2, where let A B be the base line, C D the river, and E the inaccessible object, A E and B E being the meeting lines.

Now this is all very well when the base line is long enough. For instance, suppose we took a base line of a yard in length, and we were to attempt to measure the distance of an object supposed to be 500 yards off; our base line would be too small for our purpose, at least we could not expect to measure the angles with any degree of accuracy. Fifty yards, which would be a 10th instead of a 500th, would enable us to effect our object easily. Now the only base line that we can make use of on the Earth for the purpose of establishing an angle such as that obtained by the use of the theodolite is confined within the limits of the Earth itself. This limit speaking roughly extends over about 8,000 miles, the distance of the North and South poles from each other, but as no one has ever reached either pole, much less been able to live there, we must limit our base line still more. As a matter of fact about 7,000 miles is as large a base line on the Earth's surface as we can get. Now we know the Sun is somewhere about 90,000,000 of miles off. It is obvious, therefore, that this base line is not large enough for our purpose, supposing the real distance is anything like 90,000,000 of miles, if we adopt the simple plan exemplified by the theodolite. I will now proceed to explain how, by means of the observation of the transit of Venus, we are able to effect the object in view.

Everybody knows that the distance of an object affects its *apparent* height and breadth as represented to the eye. A tree 30 feet high and 100 yards off *looks* higher than a tree of the same height 200 yards off. This we all know from actual observation and experience, and it would be waste of time to enter into a demonstrative proof of it. If, too, we know the actual height of the tree we can ascertain the distance from us by comparing its apparent height, or the angle it makes with the eye, with its actual height. These facts being apparent with regard to the tree we are ready of course to understand their applicability to the Sun, that is to say, we are ready to admit that if we can ascertain the actual diameter of the Sun, we can, by comparing it with its apparent diameter, ascertain its distance from us. I should point out that supposing the circle of the heavens to be divided into 360 degrees like our theodolite disc, the Sun does not occupy so much as one degree of it.

It has been ascertained that the distances of Venus from the Sun and the distance of the Earth from the Sun are in *proportion* of about 72 to 100 ; that is to say, if Venus is 72,000,000 of miles from the Sun the Earth is 100,000,000 of miles from it. When Venus, therefore, passes across the Sun's disc, as it will do on its transit, and one person is looking at it from the extreme North point of the Earth, and another from the extreme South, it is obvious that the two persons cannot see her projected on the Sun in the same place. In other words, the observer at the North point of the Earth will see her lower down on the face of the Sun than the observer at the South can. If it could be seen from both points at once (which, of course, is impossible), it would appear to the eye as two planets instead of one crossing the Sun, and their tracks would make a sort of band across the Sun. Now the knowledge of the length of our base line—in other words the distance between the two observers upon the face of the Earth (it having, of course, been accurately measured), coupled with the knowledge of the *proportion* of the distance of Venus from the Sun as compared with the distance of the Earth from the Sun—will enable us to measure the width of this band, and for this purpose we will assume the base line to be 7,000 miles long. Now if Venus were exactly half way between the Earth and the Sun, the width of the band would be exactly the same as the distance of the observers from each other, *i.e.* 7,000 miles. If she were nearer the Sun than half way, then the band would be *less* than 7,000 miles in width. If nearer the Earth than half way, then the band would be *more* than 7,000 miles. It happens that she is nearer the Earth than half way between it and the Sun, and in fact nearly but not quite in the relative position that three is to four; in other words, she is nearly three-fourths of our distance from the Sun, the actual proportion being very nearly, as I have already stated, as 72 to 100. To get at the actual width of the band, therefore, we must compare the number 72 to 28 (the difference between 72 and 100), and we shall find by Rule of Three sum, 28 : 72 :: 7,000 (the base line) : to the width of the band, that the band is 18,000 miles wide.

Now we have got something definite with regard to the Sun—that is to say, whatever its actual size or its distance, we have got a band upon it which is 18,000 miles wide. See diagram No. 3.

If it so happened that the observer in the North saw Venus just touch the lower part of the Sun, and the observer in the South saw it just touch the upper part of it, then clearly the Sun would be 18,000 miles in height or, what is the same thing, for the Sun is as nearly as possible a perfect circle, in breadth or diameter. Again, if one of the observers saw it cross the centre, whilst the other saw it cross at the top and just touching it, then clearly the Sun would be twice 18,000, or 36,000, miles in diameter; so again, if one observer saw it cross half way between the centre and the top, and the other saw it cross at the top, then clearly it would be four times 18,000, or 72,000, miles in diameter.

It happens, however, that Venus, as seen from the two positions, will in fact make but a comparatively narrow band across the Sun. It must be borne in mind, too, that but one of the lines forming the band will be seen from one position, and it will be impossible, if only on this account, to ascertain the diameter of the Sun by simply comparing the width of the band with the diameter of the Sun. Besides, were this difficulty non-existent, we should then have to deal with another difficulty, viz., that of ascertaining whether Venus did cross the Sun exactly in the positions we have supposed. We must therefore do something more to obtain anything like a correct estimate of the diameter of the Sun.

As we have already said, as seen from the two positions, the tracks of Venus on passing across the

Sun will produce the effect of a band across it. Supposing the lower line of the band were to be on the centre of the Sun, and the upper line to be half way between the centre and the top (and we were able to ascertain that this was so), we could by other means as well as by simply multiplying the 18,000 miles by two or four, as mentioned above, ascertain its breadth ; that is to say, if each of the two observers noted down the exact time it took the planet to cross the Sun at their respective stations, they would, on comparing notes when they met, be able to tell what *difference* there was between the two times. The difference might (say) be a quarter of an hour or it might be half an hour, and supposing the transit occupied five hours at the centre (which would, of course, be the longest of the two times), then the difference would be a twentieth or a tenth, as the case might be. The lines of the band being made by one planet, and their existence being owing only to the difference of position of the observers, it is of course obvious that the difference of times would necessarily be equal to the difference in length of the lines of the band; the difference in length, therefore, will be also one-tenth or one-twentieth, as the case may be, under the above hypothesis.

Were the planet to cross the Sun, as observed from the two positions, at an equal distance on both sides of the centre of the Sun, there would of course be no difference whatever between the two times, and the transit would be useless to us as proving, by means of the difference of times, what the diameter of the Sun is. As mentioned above, however, the band is a narrow one, comparatively speaking, and entirely on one side of the centre. Consequently there is a difference between them.

Before, however, the difference can be made use of for the purpose of measuring the diameter of the Sun, it is obvious that the points of the circumference of the Sun where the planet enters upon it, as seen from the two positions, should be carefully noted. For, of course, the nearer the centre the lines made by the planet are, the less the difference there can be between them—the further they are from the centre the greater will be the difference—this will be seen at once. Were one of the lines on the centre, and the other only to touch the top, then the difference would practically amount to half the whole time, inasmuch as it would not be till the planet had reached the centre of the disc of the Sun, as seen from one position, that it would touch the top of it as seen from the other position; and the difference of the lengths of the lines being precisely the same as the difference of times, and the difference in times being one half the difference in length, it would also be one half. Again, were the observer in the Northern Station to see the planet passing across the centre as before, and the observer in the South to see it passing half way between the centre and the top, by the same reasoning the difference would be a quarter of the whole time. We must therefore take care to note as nearly as we can about where on the Sun the planet meets it as seen from the two stations.

Now what is the inference to be derived from the facts as we have stated them? It is obvious that no two circles of different size can have the same diameter. It is equally obvious that a line drawn across a circle parallel to a line drawn through its centre, cannot possibly be equal in length to a line drawn in precisely the same place across another circle the diameter of which is greater or less than the diameter of the first circle, for if it were so the circumference of a circle would not be uniform. This being so, it is easy to see that the *difference* between the lengths of two lines drawn across one circle parallel to a line drawn through its centre, at any stated distance apart, cannot possibly be equal to the difference between the lengths of two lines drawn in the same position and the same distance apart, across any *other* circle in which the diameter differs from the first circle. In other words, the difference between the lengths of the two lines drawn across a circle, at a stated distance apart, and at a particular distance from the centre, is the key to the problem, what is the breadth or diameter of the circle. Having satisfied ourselves as to this, we ask the question, What is necessarily the diameter of a circle across which two lines, 18,000 miles apart, and drawn in the particular positions Venus has been observed from the two stations to travel, differ from each other in length to the extent they have been found to differ, and it is plain this is to be ascertained on the principle of Rule of Three sum.

Having ascertained the diameter of the Sun in this way, all that remains to be done is to ascertain its distance from us, and this is done by comparing its actual diameter with its apparent diameter. There is no more difficulty in doing it than in ascertaining the distance of a church steeple a great way off when you know its height.

Before closing this little essay it may be as well to explain that it would be impossible to obtain a base line of 7,000 miles on exactly the same meridian. This, however, will complicate the observation very little, as all that is necessary under such circumstances is to make proper allowance for the time of day.

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