THE TRANSIT OF VENUS

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WITHIN a few weeks, will occur an event universally regarded as one of the most important and interesting which can happen in the whole range of astronomical phenomena. It is the passage of the planet Venus across the disk of the sun on .the 8th of December, 1874. Only four such events have occurred since the discovery of the telescope made their observation possible. Two will occur in what remains of the present century, and then not another during the whole of the next. To show the extreme rarity of this phenomenon we give the dates of all transits occurring within 400 years.

1631, December 6.
1639, December 4.
1761, June 5.
1769, June 3.
1874. December 8.
1882, December 6.
2004. June 7.

The last occasion of this kind was on June 3, 1769. It was then considered so important that all the leading civilized nations sent out expeditions to observe it. It was one of these which was conducted by Captain Cook to the Island of Otaheite in the Southern Pacific Ocean, when observations were made at a point called to this day, Venus Point. As early as 1871, the grounds of the Greenwich Observatory were occupied by temporary structures for experimenting upon the best modes of observing. The United States have not been behind in this preparation. Special instruments have been constructed, and experiments tried, and a programme of operations has been formed. Congress appropriated funds for carrying: out this programme, and named a commission of distinguished and experienced men to direct the necessary preparations. This commission at first consisted of Rear Admiral Sands, Superintendent of the Naval Observatory; Professor Benjamin Peirce, LL.D., Superintendent of the U. S. Coast Survey; Professor Joseph Henry, LL.D., President of the National Academy of Sciences; Professor Simon Newcomb, U. S. Navy, Naval Observatory; Professor Wm. Harkness, U. S. Navy, Naval Observatory. The first two members have since February last been replaced, in consequence of their retirement from office, by Rear-Admiral C. T. H. Davis, Superintendent of the U. S. Naval Observatory, and C. P. Patterson, Superintendent of the U. S. Coast Survey. It will be the object of this paper to explain briefly and in a popular manner the nature and importance of this phenomenon, and to point out the character of the observations to be undertaken in connection with it. The relation between the times of revolution of the planets and their distances from the sun was discovered by Kepler, and is exceedingly simple, viz.: "The squares of the numbers which express the times of revolution, are to each other as the cubes of the numbers which express the distances of the planets from the sun." Now of the quantities involved in this proportion the times of revolution are easily observed, and are known with a precision which leaves little to be desired. If, then, we knew the distance of anyone of the planets, as for example that of the earth, a simple application of the rule of three would give us all the others. From the earliest ages of astronomy, this problem of the distance of the sun from the earth has attracted and baffled the ingenuity of the mathematician. And it is the more perfect solution of that problem which at present is attracting attention to the phenomenon of a transit of Venus. Aristarchus, a Grecian astronomer, B. C. 250, gave the first known answer to the question, but it is sufficient to say that his result was only about one-twentieth of the true distance. Hipparchus, of Rhodes, B. C. 150, tried a different method with a result no more nearly correct. In this condition the problem rested for centuries. The common notion was that the sun was about five millions of miles distant. In the seventeenth century Kepler could only say that the distance could not be less than thirteen and a-half millions of miles. Subsequently other estimates increased the distance to eighty and eighty-five millions. The methods employed, and the instruments then in use, were plainly inadequate to the problem. Such was the state of the question when Dr. Edmund Halley, then Professor of Astronomy at Oxford University, proposed in 1716 a method of determining the distance of the sun by the transit of Venus. It awakened great interest, and at the next ensuing transits in 1761 and 1769, it was successfully employed. Ever since it has held its place in the estimate of astronomers as the most reliable method. Other methods have, indeed, been resorted to in the long interval between the transits, and because they have been tried with instruments of such extreme delicacy, and have been guarded against error with such skill and ingenuity, they have yielded results very little, if at all, inferior to the transit method. But a new opportunity of verifying the results of past researches, which the approaching transit affords, attracts to this event unusual interest. Let us now proceed to consider how the transit of Venus may be made available for determining the distance of the sun. When a surveyor desires to ascertain some inaccessible distance; as, for instance, the width of a river, he measures a base line on his side of the river, and also the angles between this base line and the lines running to the desired point. With these data he can compute the required distance. A plan similar to this is employed when the astronomer desires to determine the distance of the moon. The base line which he uses in his computation is the radius of the earth, and the angle subtended at the moon by this radius is called the parallax. These two being once known, the distance may readily be found. But it was long ago found that the method which served well enough in the case of a near body like the moon, failed utterly when applied to a body as distant as the sun. The sun's distance was so great that the angle subtended at it by the earth's radius became inappreciable. Dr. Halley's method enabled the astronomer to employ, instead of the parallax of the sun, the parallax of Venus at her nearest point. Venus revolves in an orbit within that of the earth. Venus completes a revolution in this orbit in about 224 days, while the earth requires 365.

Fig1

Hence, in the course of their revolutions, Venus must sometimes come in a line between the earth and the sun, as at V. This is called her inferior conjunction. Again, in the course of their revolutions, Venus must sometimes come in a line with the sun and beyond it, as at V'. This is called her superior conjunction. These conjunctions occur at intervals of about 584 days. Now it is plain that when Venus is at V, and the earth at E, her distance from the earth is much less than that of the sun, and her parallax consequently much more. In fact the distance from the earth to Venus is only about one-quarter as much as that to the sun, and therefore her parallax almost four times more. It was precisely to take advantage of this greater parallax that Halley's method was proposed. The difficulty in the way is that Venus is rarely visible at her inferior conjunction. The light of the sun is so great that the brightest stars in its vicinity are lost to sight. It is only on those rare occasions, when Venus chances to come so exactly in line that her disk is projected as a black dot against the sun's disk, that she becomes an object for rigid observation. The causes for this rarity we shall explain subsequently. For the present let us assume that a transit across the sun's disk is actually under inspection from the earth. In the adjoining figure let S represent the sun and E the earth, and let the planet Venus be supposed to be moving in her orbit at V between the sun and the earth. We may further assume that the earth is stationary and that Venus moves with a velocity equal to the difference between her own and that of the earth. Let two observers be supposed to be watching the phenomenon, the one at A, a point near the North Pole, and the other at B, a point near the South Pole.

FIG. 2

It is evident that to these two observers the transit would appear to take place on different lines. Thus, the observer at A would seem to see the planet crossing in the line CD, while the observer at B would see it on the line F G. The further apart the two stations A and B could be taken, the greater would be the interval a b between the two paths. Now, suppose we knew, as we do, how much further it is from V to a than from V to A. We should know that exactly so much longer is the line a b than A B. But since the location of the two observers at A and B is known, their distance apart in miles can be found. And thus we have at once the distance a b in miles. It only remains to find out, if possible, what part a b is of the entire diameter of the sun, and then we should know this diameter in miles. We do know the angular diameter of the sun; that is, we know the angle made by two lines drawn from the eye to the two ends of the sun's diameter. Its average value is about 32', a little more than half a degree. The radius of the sun, then, is about 16'. If the observer, then, at A had timed with great precision the ingress of the planet at C, and its egress at D, he would know the time occupied in traversing the line CD. Then, knowing the rate at which the earth and Venus' move in their orbits, not in miles, but in minutes, he can tell the exact length of C D in minutes. In making this estimate he must take into account, not only the motions of the planets in their orbits, but also the effect produced by the earth's rotation. In like manner the length of the line F G can be determined in minutes. From these lengths it is easy to derive the length of a b, the distance between the two lines, in minutes. But we already know a b in miles, and from these two values we can ascertain how many miles are due to each minute or second of arc at the distance of the sun. It is about 450 miles for each second. Hence the angle subtended by the earth's radius, which is called the parallax of the sun, must be the quotient of 450 miles contained in the earth's radius, namely, about 8".9'. Such is virtually, although not precisely, the process by which the sun's parallax is derived from the transit of Venus: There are numberless considerations connected with the process which cannot be here explained. The observers are not two, but any number. The calculations are by no means so simple in practice as here indicated. Every circumstance which can possibly affect the result must be taken into account, and the most refined expedients must be resorted to in order to avoid instrumental and other errors. From observations on the transits of 1761 and 1769, Encke computed the parallax of the sun and announced it as 8".5776, corresponding to a distance of 95,274,000 miles. This value was universally accepted as possessing the highest probability. It held its place unchallenged for many years in the nautical almanacs, and in works on astronomy. By those, however, who were familiar with the defects of the observations on which this result was founded, it was not accepted as final. There were discrepancies and irregularities in these observations which prevented perfect confidence. In addition to this, all the other methods for measuring the parallax which from time to time were used with augmented precision, gave a value for the parallax considerably greater than this. Hence, it came to be understood among astronomers that Encke's value for the parallax must be replaced by a greater. Finally, in order to reconcile, if possible, the results of the different methods, a reexamination of the records, and a recomputation, were undertaken by various distinguished astronomers. Leverrier, the illustrious discoverer of Neptune; Newcomb, of the Washington Observatory; Stone, of the Greenwich Observatory, and others, contributed to this discussion. Newcomb's conclusion was a parallax of 8".848, which is the one now employed in the American Nautical Almanac. Stone put it at 8".91, which is now adopted in the British Nautical Almanac. It remains to be seen what confirmation the transits of 1874 and 1882 will afford to these modifications of the value of the parallax. The prediction of transits of Venus is a. process of exactly the same character as the prediction of eclipses. The periods of their recurrence depend upon the relative times of revolution of the earth and Venus, combined with the inclination of the planes of the two orbits to each other. It is found that these causes usually result in two transits, following each other at an interval of eight years; then, after a long interval of 235 years, another pair of transits occur in the same month, but eight years apart. Thus there were transits in December, 1631 and 1639, and now, after an interval of 235 years, two others are about to happen in December, 1874 and 1882. In the meantime, however, another pair of transits have occurred in June, 1761 and 1769, and 235 years from this another will occur in June, 2004. We cannot now enter upon the full explanation of these periods of recurrence. It must suffice to say that they can be computed with the utmost precision, so that the observers set out to their distant and often perilous posts of observation, with the most perfect assurance that at the predicted hour and minute a little black dot, scarcely larger than a fly speck on a golden eagle, will enter on and slowly cross the sun's disk. For the transit of 1874 the nautical almanacs are already issued with full details as to the times of ingress and egress for various positions on the earth's surface. It remains to consider the character of the observations which a transit like the coming one of 1874 will demand. The adjoining figure will illustrate the different phases of this transit. Let S represent the sun, and V the planet Venus moving in the direction of the arrow, while E1, E2, E3, &c., represent the earth, encountering different phases of the transit. In reality, the planet Venus moves past the earth, but, for convenience, we will conceive Venus to remain stationary and the earth to advance in an opposite direction with a velocity equal to the difference of their velocities. When the earth reaches the position E1, an observer on the most forward part would just see Venus in external contact at V1. As the earth moves forward other points on the illuminated face of the earth, as fast as they reached the line A X1, would also see the planet in external contact. When the entire earth has passed the1ine A XI, and no part yet reached A X2, at all points Venus would appear hanging on the edge of the sun's disk. When the earth reaches E2, to the most forward point Venus would appear in internal contact at A, as represented at V; and, as other points cross the line A X2, to them also the phase of internal contact would be revealed. When the earth is between A X2, and B X4, the planet would appear to all observers as projected on the disk and in the act of passing across. As the earth reaches and passes the lines B X1 and B X5, the phases of internal contact and external contact will recur in an inverted order. The time occupied in a transit will depend on the length of the chord traversed. If it were directly through the sun's center, the time might be as much as eight hours. The following times, taken from the American Nautical Almanac, will show the duration of the several phases in the transit of 1874. They are given in Washington mean time, r and apply to the center of the earth.

	H	M	S
1. External contact, ingress, Dec. 8th,	8	40	22.6
2. Internal contact, ingress.	9	10	29.2
3. Mid-transit	10	59	17.6
4. Internal contact, egress	12	48	6.7
5 External contact, egress.	13	18	13.3
6.Whole time from ingress to egress.	4	37	50.7

To obtain the times for these phases, at any station on the surface of the earth, it would be necessary to take into account the longitude, the latitude, and the radius of the earth at that point. Without an elaborate calculation of this kind, we may see from the above statement that the transit will begin about half-past eight in the evening by Washington time, and end about an hour and a quarter after midnight. To observers in the United States, therefore, it is plain that the phenomenon will be invisible, the whole taking place after sunset. The islands of the Pacific, the East Indies, Australia, and the Eastern coast of Asia, will see its beginning. To Central Asia and Africa, the sun will rise with the transit in progress, and they will see its ending. Japan and Western China and Australia will be among the fortunate places where the beginning and ending will both be visible. According to the method originally proposed by Halley, the stations to be occupied by observers ought to be only such that the entire transit may be observed from them. But by a modification of this method, stations may be used from which either the first or last contact alone can be observed. In this case, however, it is necessary to know with great precision the difference in longitude between the two places. The principle on which locations for observation are selected is, that as great a difference as possible shall exist between the length of the transit at the two places to be compared. Since the transit for 1874 is to be across the upper limb of the sun, it is evident that it will last longer to observers the farther they are to the north, and shorter to observers the farther they are south. In estimating the time of continuance for any place, the modifications introduced by the rotation of the earth must be taken into account. To obtain a clear idea of the best locations for observing the transit, proceed as follows:

Find on a terrestrial globe the point whose Longitude is 150° 57'.0 East from Greenwich, and Latitude 22° 48'.6 South.

This is the spot over which the sun is vertical at the instant of first ingress. Bring this point of the globe into the zenith. Then all places above the horizon of the globe will see the phase of ingress. To find what places will witness the phase of egress, bring the point of the earth over which the sun is vertical at the moment of last contact to the position of the zenith. This point has:

Longitude 81° 30'.0 East from Greenwich.
Latitude 22° 49'.7 South.

In this position of the globe, all points above the horizon will witness the phase of egress. All places which are above the globe horizon, in both positions, will witness the entire transit. Places which, in revolving the globe from its first into its second position, disappear below the horizon, will witness the beginning, but not the ending. Places which, in this change of the globe, come above the horizon, will witness the ending, but not the beginning of the transit. It has been found by a careful consideration of the facts, that the best stations in the northern hemisphere will be at the following places, viz.: Nertchinck, in Asiatic Russia; Tsirsikar, Kirin aula, Pekin, Canton, &c., in China; Yeddo, and other points in Japan, &c. While in the southern hemisphere, recourse must be had to such inaccessible points as South Victoria Land, Adelie Land, Sabrina, Hobart Town, Melbourne, &c. Let us turn now to the methods to be adopted in observing the transit. And here, let us recall the degree of precision which has already been attained in this problem, and the further precision which it is hoped may now be attained. The whole angle of the parallax which we wish to measure is only between 8" and 9"' We already know this angle within a few tenths of a second, probably within one-tenth. What is desired is, if possible, to make the measurement reliable, within a hundredth of a second. Now, a second of arc (1") is only the angle which is subtended by a silver half-dollar at a distance of about four miles. A tenth of a second (0".1) is the angle subtended by the same coin about forty miles distant. This is equivalent to a human hair at a distance of about 450 feet. And finally a hundredth of a second (0".01), which is what we want, if possible, in this case to make sure of, is equal only to a human hair 4,500 feet distant. For such a delicate and difficult problem, it will be useless to be content with only the ordinary instruments and the ordinary methods of observation which were in use at the last transit. It will be a waste of time and strength to equip expeditions to go literally to the ends of the earth, unless they are provided with appliances more accurate than Captain Cook and his coworkers had in 1769. We must attack the problem with all the resources which modem science has placed at our disposal. If there be anything in optical science, in micrometry, in photography, in spectrum analysis, in telegraphy, or elsewhere in the whole arsenal of human knowledge, let it be brought out, and directed with the most consummate human skill upon this resisting problem. Observations on the sun are attended with some difficulties which are peculiar. The sun is intensely hot and intensely luminous. Its surface, instead of being a smooth, unchanging globe, is constantly in a state of the most fearful agitation. The edges of its disk, therefore, at which we are to observe the ingress and egress in a transit, are ragged and irregular. Besides this, the planet having its dark face turned toward us, cannot be discovered until the contact actually begins so that the observer is apt to allow some seconds or fractions of a second to elapse before he recognizes the little stranger. This difficulty has rendered the observations for external contact notably uncertain and unreliable. But when the phases of internal contact are selected for observation, a new class of difficulties is encountered. It is found that long after the planet would seem to be clear of the line of the limb, it still clings fast to it by a dark ligament. Gradually the ligament grows thinner and thinner, until finally it breaks.

FIG. 4.

Now, what is the true moment of internal contact? Is it when the two disks are in the position of apparent tangency to each other? Or when the ligament forms? Or when it breaks? The observers of the transit of 1761 and 1769 attributed the phenomenon of the ligament to the atmosphere of Venus. It is now known to be due to what is known as irradiation. When a bright object is seen upon a dark ground it seems larger than it really is, and when a dark object is seen upon a bright ground it seems smaller than it really is. In either case the cause is the same. The bright surface, projecting itself on the retina by strongly luminous rays, affects it beyond the true boundaries of the image. The bright image will transgress the line of separation and give to the mind the sensation of being larger than it really is. We may convince ourselves of this optical fact, if we cut from a sheet of white paper a small round disk and paste it upon a dead-black ground. At the same time paste the white paper from which the disk has been removed over a black ground. We shall then have a white circle and a black one of exactly the same size. But when placed at a distance from the eye, and strongly illuminated, the white disk seems decidedly the larger. In the same way it will be found that white letters on a black surface will al- ways appear larger than black letters of the same size on a white surface. This principle, when applied to the phenomena attending a transit of Venus, explains how the sharp cusps of light between the planet and the limb of the sun seem larger than they really are. Thus in the figure the luminous limb, instead of reaching to the fine line, by irradiation reaches to the broken line; and thus a broad ligament, instead of a mere point, appears to connect the planet and the limb.

FIG 5.

With this explanation in mind, we at once see that the true moment of internal contact is at the breaking of the ligament. It has been explained that the element to be measured in a transit is the length of the line traversed by the planet, and that this is accomplished by measuring the time occupied. The observer, therefore, must be prepared to see the phenomenon and time it. He will therefore require the following instruments:

1. A telescope of sufficient power to see the bodies distinctly. It will not be possible to transport to the stations of observation the largest telescopes in use, but it is exceedingly important that observers be provided with those of excellent quality, giving clear, well defined images. The telescope should be mounted equatorially and run by clock-work, so that at

critical moments the whole attention of the observer may be free from: the work of manipulating the instrument.

2. A clock or chronometer. Time being the essential element in the problem, this is the most important of the instruments to be provided. The stations must be occupied a considerable time before and after the transit, in order that the time-pieces may be regulated and rated.

3. A chronograph. This is one of the improvements of modem astronomy, and will be one of the means by which the observers of the approaching transit will attain greater precision than heretofore. It will be possible with this help to measure the time to hundredths of a second with almost as great a certainty as tenths of a second could before he measured.

4. A transit circle. The observer must know the latitude of his station, and must have the means of regulating his clock by the stars.

5. Means for obtaining longitude. This must be got by the telegraphic method when possible; but, inasmuch as this will, in most cases, be impracticable, the observer must have recourse to all other available methods known to astronomers.

6. The spectroscope. During his observations of the eclipse of 1869, a new method of observing first and last contact suggested itself to Professor Young. The same idea had also been independently conceived by M. Faye, a distinguished French astronomer. If the spectroscope be turned upon the body of the sun, a spectrum crossed by the Fraunhofer black lines is observed: If, however, the slit of the spectroscope be turned so as to receive light from the edge only of the sun, or rather from the thin layer just outside of the visible edge of the sun then a spectrum of bright lines is seen. This layer of matter, which furnishes the bright line spectrum, Mr. Lockyer has named the chromosphere. It envelops the luminous globe on all sides, but being of inferior radiance, is not visible except in times of total eclipse. Now, Professor Young proposes to turn the spectroscope on that point of the sun's limb where the ingress of the planet is expected to occur. He proposes to select for observation some conspicuous bright line of the spectrum (for example, the line C), and as the ingress progresses, to watch for its extinguishment. As the planet advances into the chromosphere, this bright line, which at first was the whole depth of the chromosphere, will gradually be shortened. The moment of its final disappearance must be the moment of external contact, because then the planet has penetrated through the chromosphere and has entered the true photosphere.

7. Photographic apparatus. Photography has been applied to astronomy with great success for some years. Mr. Lewis M. Rutherfurd, of New York, and Mr. De La Rue, of England, have been among the earliest and most successful cultivators of celestial photography. In all the later observations on total eclipses of the sun, photography has played a leading part. Not only has photography been employed to represent the physical phenomena of the heavenly bodies, but it has also been successfully used for measuring interstellar distances. Groups of stars have been photographed (the Pleiades, for example), and the micrometric measurements made of their distances on the photographic plates have been found to possess the same order of precision as those made by micrometers in the telescope. The plan to be pursued in applying photography to the observation of the transit consists in taking a succession of photographs at short intervals, say every minute, during the progress of the transit. Each of these will show the bright disk of the sun with Venus as a little black dot on it. This dot will appear in the successive photographs to occupy points which, taken together, will form the path traversed by the planet. From these photographs, or from enlarged copies of them, measurements are to be made with suitable micrometers, of the distance and direction of the planet from the sun's center. These will give the path of the planet, and the length of this path compared with the solar diameter. This length is to be compared with similar measurements made at the stations selected for comparison. Great hopes are entertained of the superior accuracy of this method. It has one great advantage over the usual methods. They can only be applied when it is possible to see either the beginning or ending (or both) of the transit. A passing cloud, a misplaced eye-piece, or a bungling assistant, may destroy the labors and preparations of months. But in the photographic method it is possible to derive the path of the planet from a portion, and any portion, of the photographs. Of course the success of the plan will depend upon the skill with which the photographs are taken,-the

precision with which all errors arising from refraction, from expansion of the tubes and plates by heat, and from irradiation on the photographic plates, may be detected and allowed for Elaborate experiments are being conducted by the commission created by the Act of Congress. They have called into council the best talent to be found in the United States and Europe. They have constructed at the Naval Observatory apparatus with which to test the methods to be employed, as well as to train the ob- servers charged with the duty of conducting the expeditions. The mode of photographing which has been resolved upon is by means of a telescope tube laid in a fixed horizontal position. At the one end is a heliostat by which the rays of the sun are constantly projected through the tube. At the other end is fixed the photographic apparatus. This arrangement gives great advantages in manipulating the photographic plates, and in eliminating errors from the flexure of the tube. Eight parties were to set out from the United States, five for the southern, and three for the northern stations. There is, of course, a mutual understanding between astronomers of different nations in regard to the localities to be occupied. Russia has available northern stations within her own eastern territory. Great Britain has in Australia and neighboring islands available southern stations. For the American parties the following stations have been selected in the southern hemisphere, viz. Crozet Island, Kerguelen's Land, Hobart Town, at the south end of Tasmania; some point in Southern New Zealand and Chatham Island, to the east- ward of the preceding. The five parties destined for these stations sailed early in June in a naval vessel, via the Cape of Good Hope, to be left successively at their several stations in the order named, and after the event, to be taken up again in the inverse order. The three northern parties destined for Pekin, Yeddo, and Vladivostock, in the south-eastern extremity of Russian Tartary, were to take their departure in September. The transit of 1882 follows that of 1874 at such a short interval that the apparatus prepared for the first will also do service in the second. So far as the United States are concerned, the transit of 1882 will have even greater interest than that of 1874. The most favorable northern stations for observation will, in that case, be found on our own Atlantic coast and the neighboring West India Islands.