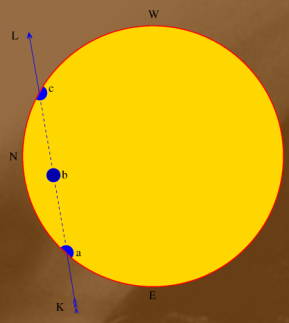
ADMINISTRATION REPORT
OF THE
MADRAS OBSERVATORY
FOR THE YEAR 1874

Transit of Venus

C. Ragoonatha Chary

Transit of Venus- As at almost every other observatory in the world at which this important event was visible, very complete and careful preparations were made in anticipation of the Madras Observatory contributing its share to the general results.

Venus was briefly seen once or twice during the transit, but only through thick clouds which rendered photographs or measurement of any kind impossible. The second internal contact, noted by Miss E. Isis Pogson and C. Ragoonatha Charry, was the only record obtainable after all the trouble incurred



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Telegraphic Longitude Determinations.- Although the Transit of Venus owing to bad weather, proved so signal and disappointing a failure at Madras so far as actual observations were concerned it still fell to the lot of the Observatory to render useful aid to more fortunate observers elsewhere, by means of telegraphic determinations of their longitude – one of the most important and yet the most difficult of all the requisite data for rendering their observations available for the determination of the solar parallax. By the obliging aid of the Government Telegraph Department

INDIAN
INSTITUTE OF
ASTROPHYSICS

Transit of Venus

C. Ragoonatha Chary

Indian Institute of Astrophysics Archives,
Bangalore

TRANSIT OF VENUS (In English)
BY C. RAGOONATHA CHARY

Original Pamphlet: 1874
Reprinted: 2012

IIA Archives Publication Series No. 3

Publisher
The Director
Indian Institute of Astrophysics
Bangalore – 560 034
India

Front cover image: Shows the path and position of Venus, when crossing the Sun's disc during its transit on the 9th December 1874. (This pamphlet figure 4)

Back cover images:

1. Explanation of parallax of terrestrial objects((This pamphlet figure 7)
2. C. Ragoonatha Chary
3. Madras Observatory

Cover design: IIA Library, Bangalore

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Foreword

Transit of planets across the disc of the Sun is one of the most fascinating phenomena in the solar system. Observations of the transit of Venus have not only a long history, but are also associated with adventurous, sometimes disastrous voyages, across the globe. Two successive transits of Venus occur every 243 years with an interval of 8 years between them. The last observed one this century (21st) in India occurred on June 8, 2004 and its twin is expected to follow 8 years later on June 6, 2012. The earlier 19th century pair of transits that occurred in 1874 and 1882, and seen in India, drew enormous public and scientific interest. The Madras Observatory, being the premier centre for astronomy those days, made elaborate arrangements for transit observations.

Chintamany Ragoonatha Chary (1828-80), who was the first assistant at the Madras observatory, was a man who possessed an enormous knowledge of both traditional sidhanthic astronomy as well as modern astronomy. He undertook to describe this beautiful celestial event and educate the public. Observations of the transits of planets (Mercury and Venus) would not have been possible before the advent of the telescope. Ragoonatha Chary, with encouragement from N. R. Pogson, then the Government astronomer at the Madras Observatory, brought out a pamphlet. Originally written in Tamil, it described with illustrations the phenomenon of transits (over the Sun), their circumstances and how they are observed. Later the pamphlet was brought out in other languages as well, that included English, Urdu, Kannada and Telugu. Ragoonatha Chary presented his treatise in a unique way as a dialogue. The aim was not only to dispel superstition related to observing such celestial phenomena, but also to bring out their importance for instance in determining the distance between the Sun and Earth (by combining observations from various places). Observations of the transits

of the planets around other stars with large aperture modern telescopes (through recording the small reduction in light intensity of the star when a planet crosses it) is a hot topic in the study of other solar like systems, origin of planets, and origin of life.

The Indian Institute of Astrophysics, has inherited this legacy and possesses copies of the pamphlet in English, Kannada and Urdu in its archives. It is felt that it would not only be appropriate to bring out such a historical document for public awareness and education before the upcoming transit of Venus on June 6, 2012 (that can be observed in many parts of the country), but also to highlight what has been achieved scientifically in the country during the last century with comparatively modest instruments.

Presently the English and Kannada versions are being brought out on this occasion which we trust would stimulate interest both in the observations of the upcoming event as well as in the wonderful science of Astronomy.

Bangalore
April 16, 2012

S. S. Hasan
Director

The Transit of Venus.

A discourse by C. Ragoonatha Chary, F.R.A.S., First Assistant Madras Observatory, Madras.

This little pamphlet, we learn from the author in the preface, "is written principally for the information of such of my countrymen as have not had the advantage of any regular course of scientific reading. My apology for writing it is that, although the class of phenomena to which the transit of Venus belongs is mentioned in Hindu treatises on astronomy, especially the Sidhanta Siromani, yet the Sidhantis or Hindu astronomers are really not familiar with the nature of this particular occurrence, and cannot predict it with even a rough approach to accuracy, happening as it does at such strange and rare intervals. They can compute Thithis (one-thirtieth part of the time the moon takes to move through a synodical revolution), Nakshathras (lunar mansions of one-twenty-seventh part of circumference of the ecliptic), &c., for a Punchangum (a Hindu calendar), and can predict ordinary solar and lunar eclipses. Under these circumstances I may be excused for hoping my simple account will be found interesting to native astronomers, and not unacceptable also to general readers of other than the native community. Having been accustomed for many years to discuss astronomical facts and methods verbally with Hindu professors of the art, my present sketch has naturally, as it were, taken the form of a dialogue; but in the Sanscrit, Canavese, Malayalum, and Maharathi versions I have found it convenient to vary the arrangement.

"The sketch was first drafted in Tamil, and then translated into English and the other languages. My sincere thanks are due to my immediate superior, N. R. Pogson, Esq., F.R.A.S., the Government Astronomer at Madras, for his kind scrutiny of the piece, and for his kind recommendation of it to the government of Fort St. George; and also to the gentlemen named in the margin,* for their aid in making translations into the various languages in which I am publishing.

* Mr. C. Nagogi Row, B.A.; Mr. C. Tiruvencatachaviar, B.A., B.L.; Mr. A. Sooba Rao, B.A.; Mr. Mahadeva Muvaswava Kuntay, B.A. (Poona); Mr. Ganesh J. Agash (Poona.)

It might not be out of place to mention here that I am engaged in writing a treatise (to be styled Jyothisha Chinthamany) containing rules, formulae and tables based on the English methods of calculation for the guidance of our Sidhantis. As the cost of publication will overtax my very slender means, a number of influential native gentlemen met at Pacheappah's Hall some months ago to consider what means should be adopted to obtain the necessary funds, as well as to establish an Observatory, to serve as a school for the instruction of Hindu students desirous to qualify in practical Astronomy. On that occasion an address (the substance of which is appended to this pamphlet in slightly modified form) was read by me, a Society was formed of which the Hon'ble V. Ramienger, C.S.L., was elected President, R. Raghunatha Rao, Esq., Secretary and Sir T. Mathava Rao, K. C. S. L., T. Moothoosawmy Iyer, Esq., B.L., P. Chentsal Rao, Esq., M. Venkatsawmy Naidu, Esq., M. Ramaswamy Naidu, Esq., Y. Venketramiah, Esq., D. Sashiengar, Esq., and other well known gentlemen became members. I earnestly commend this movement to all native noblemen and wealthy gentlemen in this Presidency as well as throughout India, who are interested in the improvement of their fellow countrymen, and beg them to join heartily in a design which aims at promoting a most fascinating branch of knowledge, the cultivation of which, although under besetting difficulties and imperfections, is now and always has been highly prized by Hindus throughout the country.

To this pamphlet is also appended a memorandum of the times of the two next ensuing solar eclipses (one in October of this year, the other in the following April) for a few principal places in India, which will show that calculations on modern methods are far more reliable than results worked out by Sidhantis from ancient tables.

I must not conclude without an expression of my genuine gratitude to J. E. Cooke, Esq., the Deputy Accountant General of Madras, a gentleman who takes a keen interest in Astronomy and who has secured me valuable encouragement and support from quarters I could not have reached without his help.

C. R.

THE TRANSIT OF VENUS.

1. *Pandit.* – Sidhanti Avaul, Namaskaram.

2. *Sidhanti.* – Namaskaram, Pray sit down. What is your business?

3. *Pan.* – I have come from one of the Southern districts. I am known there as Varuna Pandit, or as Varuna Josier. I have long had a desire to have a talk with you about your Punchangum. If you permit me, I shall trouble you to explain a few things and to give some account of the astronomical phenomenon which you call the Transit of Venus across the Sun's disc, and which you say, in your Punchangum, will happen in December next, as I have not found the subject treated in any Hindu book on Astronomy.

4. *Sid.*– I am generally very happy to talk to such as are anxious to extend their knowledge of Astronomy. I believe you have read the principal Hindu treatises on the subject, and know the true causes of the eclipses of the Sun and Moon.

5. *Pan.*– I have read Surya-Sidhantum, Arya-bhateeum and Sidhanta Siromani. I know how to compute Thithi, Nakshtrum, eclipses, conjunctions, and other necessary materials for a Punchangum. I was much enlightened by the perusal of your pamphlet on the Total Eclipse of the Sun of 1871. A Solar eclipse is caused by the intervention of the Moon between the Sun and Earth, and a Lunar eclipse by the coming of the Earth between the Sun and the Moon. So it is mentioned in our Shastras. It is only the ignorant who, from the allegorical

expressions in the Puranas, say that Serpents Rahu and Kethu swallow the heavenly bodies, and after a time release them.

6. *Sid.* – I have said a little about the Transit of Venus in my pamphlet which I have referred to; and in the chapter on Conjunctions of Planets in Surya-Sidhantum and Sidhanta Siromani, the general nature of such phenomena is explained.

7. *Pan.* – I have seen what you have stated in your pamphlet. In Surya-Sidhantum and Sidhanta Siromani, in the chapters you refer to, it is stated that Bhetha Yogum and Bhetha Yuthum of planets, that is one planet crossing the disc of other, occur. But no mention is made of the Transit of Venus across the Sun's disc.

8. *Sid.* – The Transit of Venus is one of such phenomena.

9. *Pan.* – Why is it not specially treated of in our books?

10. Sid. – Simply because our astronomers, not having accurately determined the true orbit of the planets, their periods, &c., could not compute the time of such occurrences, Moreover this phenomenon is a very rare one.

11. *Pan.* – Will you please explain how it is caused?

12. *Sid.* – Yes, I will. The numberless stars that we see in the firmament, are all supposed to be centres of different systems. They are of immense size, and are at very great distance from each other. Our Sun only one of such heavenly bodies. The Sun and stars are called

Maha Grahms or mighty planets as they shine by their own light. To come to our own system, the primary planets revolve round the Sun. Mercury is the nearest to the Sun, Venus comes next, then our Earth, then Mars, Jupiter and Saturn in order. Round some of these again revolve secondary planets, called Satellites. The primary and secondary planets are non-luminous bodies; therefore only these hemispheres that are turned towards the Sun are illuminated by his light.

Vide Figs. 1 and 2

13. *Pan.* – Do the planets revolve from left to right or from right to left around the Sun?

14. *Sid.* – It is really a difficult question to answer; but I will try to give you some idea of the direction in which they revolve. By carefully observing the stars, you will find that they appear to describe a complete revolution in a day. One of them, however, appears to be stationary. That star is Polaris. Supposing you stand with your face towards it, you see the north, your right is the east, your left is the west, and your back is turned towards the south. Having determined the cardinal points, let us watch a planet's motion among the stars. It will generally move in an easterly direction, that is, from right to left if you face the south, and will travel quite round the heavens until it returns to nearly the same position. The time thus occupied will show one revolution of the planet round the Sun; but I must tell you that it does not appear to move uniformly, for though it usually moves towards the east at certain times, it will slacken its pace, become stationary, and for some little time will even appear to go westward or from left to right; but this is only caused by the earth's motion in her

orbit being such time faster than that of the planet. In any one year the motion eastward will be greatly in excess, and if the planet were viewed from the fixed Sun instead of from the moving Earth, its apparent motion would be always to the left hand amongst the stars and nearly uniform. Of course the motion would be contrary, i.e., left to right for a person facing the north. The path in which a planet moves is called its orbit, and the time it takes to describe one complete revolution, is called its periodic time. The distance of Venus from the Sun is nearly 68 millions of miles, while that of the Earth is 95 millions. The periodic time of Venus is 224 days 16 hours 49 minutes and 8 seconds; that of the Earth, called also its sidereal year, 365 days 6 hours 9 minutes and 10 seconds.

15. When Venus is in the line between the Sun and the Earth, she is said to be in inferior conjunction with the Sun, and when she is in the same line but on the other side of the Sun, she is said to be in superior conjunction. At inferior conjunction she is only 27 millions of miles distant from the Earth. Being then nearest to us, she will appear bigger than at any other time; but her bright half is turned away from us, so that, if we could see the planet at all, it would be her unilluminated side. It is true that at superior conjunction the bright half of Venus is turned towards us; but she is then 163 millions of miles from the Earth, and appears very small on account of this vast distance, and also we cannot see her owing to her apparent proximity to the Sun his much stronger light.

16. If the orbit of Venus were in the same plane with that of the Earth, then at every inferior conjunction, we should see a transit of the planet over the Sun's disc. But the orbit of Venus is inclined to that of the Earth at an

angle of 3" 23'. The two points where the orbital planes cross each other are called Nodes. At most inferior conjunctions Venus is a little removed to the north or south of the node, and therefore passes above or below the Sun, and so there is no transit; but if Venus happens to be, at the time of inferior conjunction, at or near either of the nodes, she will then be seen to cross the Sun's disc from east to west as a dark spot. This phenomenon is called a "Transit of Venus." The time of such occurrence and the places, on the earth's surface, where it will be visible, can be determined by calculation.

17. *Pan.* – Can you call this an eclipse of the Sun?

18. *Sid.* – Yes. You can call it an Annular eclipse, if you like. The Transit of Venus very much resembles an Annular eclipse of the Sun caused by the Moon. A conical shadow is cast by Venus and is turned towards us at the time of inferior conjunction. Imagine a person standing in the shadow, he will not see the Sun at all, and the Sun will, therefore, be totally eclipsed to him. But if the person is a little on either side of the shadow, he will see a partial eclipse of the Sun; and if he is beyond the end of the conical shadow, then he will see an Annular eclipse of the Sun, and the portion obscured will decrease as he recedes from Venus till when he reaches the Earth the planet's disc will have diminished so much in apparent size as to be seen only as a dark round spot.

Vide Fig. 3

19. *Pan.* – Now I know something about the transit of Venus. You say it is a phenomenon occurring rarely. When did it last happen and when will it occur next after the one in December?

20. *Sid.* – The intervals that must elapse between successive Transits of Venus are in the following series – 121 ½ years, 8 years, 105 ½ years, 8 years, 121 ½ years, 8 years, 105 ½ years, 8 years and so on. The last, which occurred on June 3rd 1769, was visible here; the next one, which will happen on the 9th of December this year, will be visible to us, but not to those in Europe. There will be one in 1882 which will not be visible in India, and the next will occur 121 years after that, viz., in A. D. 2004.

21. *Pan.* – So this is the only opportunity we have of witnessing this phenomenon. It will not seen by three more generations. What are the respective magnitudes of the Sun and Venus, and what portion of the Sun's disc will be darkened by Venus during her transit?

22. *Sid.* – The diameters of the Earth and Venus are 7,024 and 7,700 miles, respectively; therefore they are nearly of the same size. The diameter of the Sun which is immensely larger than any planet revolving round him is about 882,000 miles or nearly 111 times that of the Earth; and his volume is 1,400,000 times as great as that of the Earth. The apparent diameters of the Sun and Venus are not proportionate to their true diameters, as their distances from the Earth are different. The farther an object is, the smaller it looks. Roughly speaking, the apparent diameter of the Sun, as measured by a Micrometer, (an instrument used to measure small distances between celestial objects) is 32 minutes, while that of Venus at inferior conjunction will be one minute in space. The breadth of the black spot at the time of transit will, therefore, be about 1/22 of the Sun's diameter.

23. *Pan.* – Will it be visible to the naked eye?

24. *Sid.* – Yes. You must only take care to look at the Sun through a dark glass; otherwise your eyes will be dazzled.

25. *Pan.* – What are those curious phenomena, which you say in your Punchangum, can be seen at the time of the transit with the aid of a telescope.

26. *Sid.* – You will see the whole thing beautifully through a telescope with a dark glass attached to the eyepiece. When the centre of Venus is in contact with the Sun's limb both at ingress and egress, the planet will be seen as an indentation or break in the Sun's limb as shown at a. and c. in Fig. 4. Venus will present different forms, see Fig. 5, when she is in internal contact with the sun at both ingress and egress; these varying forms will last only for a few seconds, after which Venus will resume her shape as a round spot. The shape of Venus at ingress and egress observed and recorded by Astronomers on previous occasions differ from each other very considerably, and this difference was not satisfactorily accounted for till very lately. Some time back Sir G. B. Airy, the Astronomer Royal of England, constructed an ingenious apparatus to represent the Transit of Venus with a view to training observers as to what to expect upon all-important occasion, and the use of this apparatus showed that the variations in the shape of Venus were mere optical illusions.

Fig. 4 and 5.

27. *Pan.* – I wish to see a telescope. Can you take me to the observatory?

28. *Sid.* – I do not think I can. But I will show you the instruments in my possession. I keep some at home expressly for the purpose of explaining to our countrymen

their nature and use. One of them is a five foot equatorial telescope through which I will show you the Moon, some of the planets and stars to-night, and you can see the Sun to-morrow.

29. *Pan.* – Last night I learnt the use of a telescope; and the heavenly bodies, namely, planets, stars, clusters and nebulae, when seen through it, presented a very glorious appearance. A telescope practically brings a distant object near to us. Just as a mountain which looks smooth in the distance presents a rugged appearance when the spectator approaches it, so too, the tender crescent of the Moon which looked very even and regular to the naked eye presented a very uneven surface when seen through the telescope. The horns of the crescent which appeared sharp to the naked eye looked split, and some places detached bright spots resembling stars were seen. Near the concave rim of the crescent I saw something resembling the eye in a peacock's tail, bubbles of water and carded cotton. The planets, which when seen with the naked eye, resembled stars, appeared with well-defined limbs through the telescope. Mercury and Venus were of a crescent-shape, and I was delighted to see Jupiter with his belts and four satellites, and Saturn with his beautiful rings. Will you please show me the Sun with the telescope?

30. *Sid.* – Well. I have now pointed the telescope to the Sun, and you can look at him, but take care to look through the dark glass; otherwise you will injure your sight.

31. *Pan.* – Ah! I see a large spot on the surface of the Sun. Is there any Transit of Venus now?

32. *Sid.* – There is none now. You will see some more, if you observe carefully. These are spots on the

Sun's surface, which vary from time to time both in number and in size. They are of very irregular shape, with penumbrae around them. The black spot which will be seen on the Sun at the time of the Transit of Venus will appear much bigger and will be perfectly round with well-defined pitchdark edges.

33. *Pan.* – By the bye, I can see that big spot with the naked eye. I shall measure its diameter with the micrometer as you have taught me to do. I find it is 28 ¾* seconds in space. If, as you say, the diameter of Venus is 60 seconds, it must be twice as large as this, and one can easily see the ensuing transit without the aid of a telescope, but the day must be fine. You say, in your pamphlet on the Solar Eclipse of 1871, that Europeans were making grand preparations to observe the approaching Transit of Venus. Is it simply for the sake of curiosity that they put themselves to so much trouble and expense?

34. *Sid.* – Europeans generally put their money to very good use. You must not suppose that the practical people, who have constructed so many thousands of miles of Railway, and who have almost annihilated distance by means of the Electric Telegraph, will spend millions of rupees merely to satisfy their curiosity. They expect much practical good to result from the observations of the approaching transits as they furnish the best means we have of accurately determining the parallax of the Sun, and hence the distance and dimensions of the Sun and the planets.

35. *Pan.*–You said that the distance of the earth from the Sun was 95 millions of miles, and the distances of the other planets are also determined. Is not this sufficient?

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*This is the actual measurement taken by the Author, of a spot on the Sun which was visible to the naked eye on the morning of 20th June 1872

36. *Sid.* – Only the approximate distances are known. The last transit of Venus occurred 105 year ago. The instruments that were then used were inferior in both size and quality to those we now possess; therefore the observation made with such instruments could not be very accurate. With the delicate instruments now in use we can find out with very great accuracy the distances and magnitudes of the planets and satellites; then the calculated positions of the planets corrected for the perturbations which they produce upon each other will agree with actual observation. It is for this reason that they are about to spend such an enormous sum of money.

37. *Pan.* – The time given in your Punchangum, of Solar and Lunar Eclipses and other Astronomical phenomena, is accurate. It follows, them, that the calculated distances of the planets from the Sun are right. Where then is the necessity of expending so much to take observations of the coming Transit of Venus?

38. *Sid.* – If you had observed any of these phenomena with a telescope, then you would have found that the time given by me was not quite accurate, but that there was generally a difference of some seconds. The observations of the next Transit of Venus will lessen even this small error

39. *Pan.* – Ah, Sidhanti | Some ignorant men among us despise the European and call him a heenah, but after what I have heard from you I cannot help having the greatest respect for his industry, intelligence, and laudable attempts to extend human knowledge. Bhaskarachariar says in Sidhanta Siromani that the distance of planets from the earth can be found by means

of a pole. And as an illustration, he tells us how to determine the distance of a distant terrestrial object from us. How will the Transit of Venus enable us to determine the distance of the Sun and all the planets from the earth?

40. *Sid.* – We find out first the true parallax of the Sun and its distance from us from which we can find the true distances of all the other planets. I shall first tell you what parallax means. Supposing you stand at A and look at an object C on the surface of the earth, then you see it projected to D, a point in the horizon, say a star. The horizon is a circle of an indefinite radius having your eye for its centre. Supposing you change your position from A to B you will see C referred to E another point in the horizon. This change in the apparent position of C from D to E resulting from your going from A to B is called the parallax of C; it is measured by the arc DE. Suppose BA is produced to meet the celestial vault in S. Then the angular distance of D (the apparent position of C when you are at A) from S may be expressed by the arc SD or by the angle SAD; and the angular distance of E (the apparent position of C when you are at B) from S may be represented by the arc SE or the angle SBE. This change in the apparent position of C, on account of your moving from A to B, may be represented by the arc ED, the difference of arcs SE and SD, or by the angle ACB, the difference of the angles SAD and SBE. The parallax of C in such a case is generally represented by ACB, the angle which AB subtends at C. Take another object K in a line with ACD but farther from A than C. When you are at B, you will see it projected to *n* in the horizon. The parallax of K is D*n*. You find that D*n* less than DE, the parallax of C.

Vide Fig. 6.

Thus the more distant the object, the less the parallax. Again, suppose you move along AB to a point P, then you will see C referred to a point *m* in the horizon. The parallax of C on account of your change of position from the A to P is the arc D*m*, and this is greater than DE. Thus the more you are moved from A, the greater is the parallax of C. What we mean by the parallax of a heavenly body seen from a point on the surface of the earth, is the change in the positions of that body as seen from that point and the centre of the earth, and is represented by the angle which the radius of the earth subtends at that body. It is zero when the heavenly body is in the zenith. It is greatest when it is on the horizon, and is then called the Horizontal Parallax. Now I shall tell you how to determine the parallax of the Sun by observations of the Transit of Venus.

41. *Sid.* – In Fig. 8, BADE is the circumference of the earth's equator, C is the earth's centre, V is Venus, KL represents a portion of her orbit, S the eastern limb of the Sun, and ONM a circle of the celestial vault. Suppose that the centre of Venus is in contact with the Sun's eastern limb to a person at A, when both objects are transiting his meridian; he will refer them to the point M in the celestial vault. Suppose another person to be stationed at D, 90^0 to the west of A. When the observer at A sees Venus in contact with the Sun's limb, the Sun will have just completely risen to the person at D, N, will be the apparent position of the Sun's eastern limb, and, if it were possible for him to see Venus, he would refer her to the point O in the celestial vault. This deviation in the position of the Sun and Venus is due to parallax. To the person at D the horizontal parallax of

Fig. 8

Venus can be measured by the arc OM, and that of the Sun by the arc NM. Therefore the difference of parallax is represented by the arc ON. If there was no parallax, then the moment of contact of Venus with the Sun's eastern limb as observed at D and A, would be the same in absolute time (The local time of D would be six hours previous to that of A; the difference in longitude being 90°). But on account of parallax, Venus, which is nearer, appears depressed more that the Sun's eastern limb. The person at D does not, on account of parallax, see Venus in contact with the Sun at the time that the one at A does. The time that elapses before he sees the contact of Venus with the Sun, would be that which Venus takes to describe an arc ON in the heavens. This interval is ascertained by comparing the moment when Venus is observed to be in contact with the Sun's limb at A with that at which the same phenomenon is seen to occur at D. We know the relative motion of Venus, i.e., the rate at which she appears to overtake the Sun at the time of the transit, and thus we can calculate the magnitude of the arc ON that is traversed by Venus, and the number of minutes and seconds in it. This is the difference of the horizontal parallax of Venus and the Sun.

42. *Sid.* – It is a law of nature discovered by the illustrious German astronomer Kepler, that the squares of the periodic times of planets are to one another as the cubes of their mean distances from the Sun. The periodic times of all the planets have been well ascertained by observations. Thus we know the ratios of the distance of the Earth from the Sun to the distances of all the other planets from him. Then, if the Earth's mean distance from the Sun be divided into 1,000 equal parts, the mean dis-

tance of Mercury from the Sun must be equal to 387 of these parts that of Venus to 723, of Mars 1,524, Jupiter 5,203, and of Saturn 9,539. When therefore, the true distance in miles of any planet from the Sun is known, we can by these proportions find the mean distances in miles of all the rest. The distances of all celestial objects from us vary inversely as the sines of their horizontal parallax, and the sines vary similar as the angles themselves the parallax of all the planets being less than one minute, therefore the parallax of any planet is to that of the Sun, as the distance of the Sun is to that of the planet from us. Now, at the time of transit the parallax of Venus will be to that of the Sun, as the Sun's distance is to distance of Venus from us; namely, as 1,000 to 277, according to our supposition. Therefore the parallax of Venus minus that of the Sun, i.e., the relative parallax of the two bodies is to the Sun's; as 1,000 – 277 or 723 to 277;

$$\text{That is } \frac{\text{Relative Horizontal Parallax}}{\text{Sun's Horizontal Parallax}} - \frac{723}{277}$$

Therefore, if we divide the Relative Horizontal Parallax by $\frac{723}{277}$ =2.61, we get the Sun's Horizontal Parallax. Now the difference between the Horizontal Parallax of Venus and that of the Sun is found, from observation of the Transit of Venus, in the manner above mentioned. The number 2.61 is not the correct divisor for the day of observation, but we can readily find it by the help of any Ephemeris, such as the Nautical Almanac. Thus we get the Sun's Horizontal Parallax. Now the sine of the Horizontal

$$\text{Parallax of the Sun} = \frac{\text{Earth's radius in miles}}{\text{Sun's distance from the Earth}}$$

Therefore the Sun's distance

$$= \frac{\text{Earth's radius in miles}}{\text{Sine of Sun's Horizontal Parallax}}$$

and thus the distance in miles of the Sun from the Earth is found. The law stated above gives us at once distances of the other planets from Sun, and their horizontal parallax. Now it is not difficult to find their true diameters in miles and their volumes. We can measure with a Micrometer the angle which a planet's diameter subtends at our eye. This angle is to the true diameter of the planet, as its horizontal parallax is to the Earth's radius; *i.e.,* the true diameter of the planet

$$= \left.\begin{matrix}\text{The Earth's} \\ \text{radius in miles.}\end{matrix}\right\} \times \frac{\text{Planet's apparent Diameter}}{\text{Planet's Horizontal Parallax}}$$

The cubical content of a planet or its volume is found by multiplying the square of its diameter by its circumference and dividing by six; or the volume = $3\pi r3$, r being the radius and π being 3.14159. Thus the earth's distance from the Sun being known, the magnitudes of all the other planets, and their distances from the Sun are determined.

43. *Pan.* – Can we choose places on the earth's surface answering to A and D in the Figure?

44. *Sid.* – No, I took an imaginary case. I supposed that Venus was in contact with the Sun's limb when she was in the meridian of A; and that a man was stationed exactly 90° to the west of A. In practice we can only choose places that answer nearly to the conditions I have assumed, and the necessary amount of calculation we have to go through in finding the parallax of the Sun by means of the Transit of Venus is very complicated. The least correction on account of change of right ascension,

declination, &c., ought not to be neglected, as an error of one-tenth of a second in the Parallax of the Sun would lead to an error of about a million of miles in his distance. But I cannot now enter into details, nor would you like to be worried with them. There are several other methods of determining the Sun's Parallax from the observation of Transit of Venus. I will briefly describe one of them. Supposing two observers are stationed as distant as possible from each other in opposite latitudes; each can determine the least distance of Venus on the Sun's disc from his centre, either by noting the time of the duration of transit, or by actual measurement with a Micrometer of her distance from the limb of the Sun. The difference in the distances, as found by the two observers, being due to relative parallax, the Sun's horizontal parallax can be determined by calculation.

45. *Sid.* – The Transit of Venus being the best means we have of accurately determining the distance of the planets from the Sun, preparations on grand scale are being made by the several Governments of Europe for the observations of the approaching Transit of Venus. The Observers are to be supplied with the best instruments of recent construction, to reduce the uncertainty arising from instrumental defects to the smallest possible amount.

46. *Pan.* – I had till now a belief that it was madness to suppose that the magnitudes of such distant objects as the planets and, what is still more remarkable, their distance from the Sun could be found. Will you please give me some idea of the nature of the preparations Europeans are making to take observations of the approaching Transit of Venus?

47. *Sid.* – Though the next Transit of Venus will be only partially visible in Europe, still the different Governments have selected several stations in this continents at which observations are desirable. England has chosen 9, America 8, France 5, Germany 6, Russia 27, Italy 2, Portugal 2, Lord Lindsay has equipped two stations for observations and has gone with an expedition to Mauritius at his own expense, and numerous scientific Europeans will take observations at different stations at their own cost. The total number of places already decided upon is about 80. They are at great distances from each other. Thus, for instance, we have Alexandria, in Latitude 31° North, and Longitude 50° West of Madras; the Island of Rodrigues, near Mauritius, in Latitude 20° South and Longitude 17° West of Madras; and Honolulu, a town in the Sandwich Islands, in Latitude 21° North, and Longitude 122° East of Madras. At Madras, although the transit is visible throughout, the geographical position of the place renders ordinary observations only of secondary value, though, of course, all will be done that is possible by the Government Astronomer N.R.Pogson, Esq., F. R. A. S., and his Assistants, especially as regards the applications of photography to securing instantaneous records of the position of Venus upon the Sun's disc frequently throughout the transit. The most important spot in India has been shown to be Peshawur, and accordingly both this station and Roorkee will be occupied by Colonel Tennant, F. R. S., assisted by officers of the Trigonometrical Survey of India. An astronomer with two or more assistants and an establishment will be located at each station some months before the date of the transit. The nature of the work that each has to do, has, of course, been previously arranged. A small observatory must be

erected at each station and the necessary instruments fixed and everything kept ready for the precious day observation. The total cost of these expeditions is estimated at about 30 lakhs of Rupees.

48. *Sid.* – Each party will take with it the necessary apparatus, instruments, clocks and chronometers to determine the latitude and longitude of the places, local time, and to observe and photograph the different phenomena that may be visible at the time of transit. The chief appliances are Meridianal instruments, Altazimuth Circles, Heliographic Instruments, Equatorial telescopes with Micrometers, Photographic apparatus, Spectroscopes, Astronomical Clocks and Chronometers, Barometers, Thermometers, and other minor Instruments. With the help of these they will take accurate observations, both at ingress and egress, of the external and internal contacts (more especially the latter) of Venus with the Sun. The cusp measurements of the Sun's limb will be taken by the Micrometer. The apparent diameters of Venus will be measured. Several photographs of the image of the Sun different stages of the transit will be secured. In short, nothing will be neglected that is worth observing, but every phenomenon that can present itself, whether foreseen or otherwise during the time of transit, will be most scrupulously recorded.

49. *Pan.* – It is no wonder that the people of Europe are so much in advance, seeing how persevering they are, and how many public-spirited men there are among them. What Hindu gentleman of the present day evinces the same interest in science that the European does? Are there men among us who will devote their whole life and fortune to advance human knowledge ? Unfortunately the

answer is that there are few such men. I am wandering away from my present purpose. Will you kindly tell me when and at what point of the limb Venus will appear to enter the Sun's disc for each of the towns in India?

50. *Sid.* – In the approaching Transit of Venus which is to take place on the morning of 9th December next, the extreme difference in the time of observation of the same phenomenon at any two places on the Earth's surface will not exceed 20 minutes; the greatest difference in the time of observation in India will be about 4 minutes, absolute time being taken. The point, at which Venus will appear to enter the Sun's disc and emerge from it, will be nearly the same for all places in India. The point of ingress will be about 50° to the East of the northernmost point of the Sun's limb or 120° to the left of his vertex; and that of egress will be 22° to the west of his northernmost point, or 16° to the right of his vertex. At the middle of the transit the centre of Venus will be about 2 ½ minutes in space from the northern limb of the Sun, or at a distance of $^1/_{12}$ of his diameter. At different localities in India the time of ingress will be within an hour and a half after sunrise, and that of egress will be within an hour before or after the Sun's meridian passage. The duration of transit will be from *4h. 40m.* to *4h. 47m.* and the interval of time between external and internal contact of Venus with the Sun both at ingress and egress will be 28 minutes. The accompanying Table gives the local time of the ingress and egress of the centre of Venus, the time of sunrise, and the time and the length of the shadow of a twelve inch rod at the middle of the transit for the principal towns in India.

Vide Fig. 4.

TABLE showing the LOCAL MEAN TIME &c., of the Transit of Venus occurring on the 9th December 1874, for the places in India:--

No	Places.	North Latitude	Difference of long. to convert Local into Madrsa Time	LOCAL MEAN TIME				Shadow length of a 12 Inch Rod at Middle of Transit
				Sun-rise	Ingress of Venus Centre	Middle of Transit	Egress of Venus Centre	
				h. m	*h. m*	*h. m*	*h. m*	*Inches.*
1.	Agra ...	27 10	+ 9	6. 42	7. 15	9. 25	11. 33	22.0
2.	Ajmeer ...	26 27	+ 22	6. 41	7. 4	9. 12	11. 20	23.5
3.	Allahabad ...	25 26	- 7	6. 28	7. 32	9. 41	11. 48	19.1
4.	Ambala ...	30 21	+ 14	6. 49	7. 10	9. 20	11. 28	25.6
5.	Bangalore ...	12 68	+ 11	6. 14	7. 15	9. 23	11. 29	15.0
6.	Bellary ...	15. 9	+ 13	6. 18	7. 13	9. 21	11. 27	16.0
7.	Banares ...	25. 18	- 11	6. 38	7. 36	9. 45	11. 52	18.6
8.	Bhopal ...	23. 13	+ 11	6. 34	7. 15	9. 23	11. 30	19.9
9.	Bombay ...	18. 54	+ 30	6. 56	6. 56	9. 4	11. 11	19.8
10.	Cabul ...	34. 27	+ 44	6. 69	6. 40	8. 56	10. 59	36.6
11.	Calcutta ...	22. 23	- 32	6. 33	7. 56	10. 5	12. 13	15.6
12.	Calicut ...	11. 15	+ 18	6. 11	7. 9	9. 16	11. 22	15.0
13.	Cashmere ...	34. 5	+ 22	6. 58	7. 1	9. 12	11. 21	30.6
14.	Cochin ...	9. 58	+ 16	6. 9	7. 11	9. 18	11. 23	14.2
15.	Coimbatore ...	11. 1	+ 13	6. 11	7. 14	9. 21	11. 26	14.5
16.	Colombo ...	6. 37	+ 2	6. 4	7. 25	9. 32	11. 37	12.8
17.	Cuddupah ...	14. 20	+ 6	6. 17	7. 20	9. 28	11. 34	15.0
18.	Darjeeling ...	27. 3	- 32	6. 42	7. 55	10. 5	12. 14	18.1
19.	Delhi ...	28. 29	+ 12	6. 40	7. 12	9. 22	11. 30	28.5
20.	Gallo ...	6. 3	0	6. 3	7. 27	9. 34	11. 39	11.9
21.	Ganjam ...	19. 22	- 20	6. 26	7. 45	9. 53	12. 1	15.1
22.	Gaya ...	24. 49	- 19	6. 37	7. 44	9. 53	12. 0	17.5
23.	Gowhatti ...	26. 6	- 46	6. 40	8. 10	10. 18	12. 27	16.4
24.	Guntore ...	16. 18	- 1	6. 20	7. 27	9. 35	11. 42	15.2
25.	Hyderabad ...	17. 27	+ 7	6. 22	7. 19	9. 27	11. 34	16.3
26.	Indore ...	22. 12	+ 18	6. 32	7. 8	9. 16	11. 23	20.0
27.	Kurnool ...	15. 50	+ 9	6. 19	7. 17	9. 25	11. 31	15.7
28.	Karrachi ...	24. 49	+ 53	6. 37	6. 33	8. 41	10. 48	27.7
29.	Lahore ...	31. 31	+ 24	6. 52	7. 0	9. 10	11. 19	28.1
30.	Lucknow ...	26. 51	- 3	6. 42	7. 28	9. 37	11. 45	20.5
31.	Madras ...	13. 4	0	6. 15	7. 26	9. 33	11. 40	14.2
32.	Madura ...	9. 55	+ 9	6. 9	7. 18	9. 25	11. 30	13.8
33.	Mangalore ...	12. 52	+ 22	6. 14	7. 5	9. 12	11. 18	16.2
34.	Multan ...	30. 10	+ 35	6. 49	6. 43	8. 59	11. 7	28.8
35.	Mysore ...	12. 18	+ 14	6. 13	7. 13	9. 20	11. 26	14.7
36.	Nagpore ...	21. 10	+ 5	6. 30	7. 21	9. 20	11. 36	18.0
37.	Nellore ...	14. 28	+ 1	6. 17	7. 25	9. 33	11. 39	14.6
38.	Peshawar ...	34. 3	+ 35	6. 58	6. 49	8. 59	11. 8	33.6
39.	Pondicherry ...	11. 56	+ 3	6. 13	7. 21	9. 33	11. 38	14.1
40.	Rajahmundry ...	17. 11	- 6	6. 22	7. 32	9. 40	11. 47	15.1
41.	Sagar ...	23. 50	+ 6	6. 34	7. 20	9. 28	11. 35	19.5
42.	Salem ...	11. 39	+ 8	6. 12	7. 19	9. 26	11. 32	14.3
43.	Simla ...	31. 6	+ 12	6. 52	7. 12	9. 22	11. 31	26.0
44.	Surat ...	21. 10	+ 30	6. 30	6. 58	9. 4	11. 11	18.9
45.	Tanjore ...	10. 17	+ 4	6. 11	7. 23	9. 30	11. 35	13.6
46.	Timrur ...	26. 6	- 21	6. 40	7. 45	9. 54	12. 2	13.4
47.	Tinnerelly ...	8. 44	+ 14	6. 7	7. 17	9. 24	11. 20	13.6
48.	Tirupaty ...	13. 36	+ 3	6. 16	7. 23	9. 31	11. 37	14.5
49.	Trivendrum ...	8. 31	+ 13	6. 7	7. 14	9. 21	11. 26	18.6
50.	Vizianagarum ...	18. 0	- 13	6. 24	7. 39	9. 47	11. 34	15.2

In the above table the time of ingress and egress of the centre of Venus is given. If you wish to find the time of external or internal contact of Venus with the Sun, you have to add or subtract 14 minutes, as the case may be.

52. *Pan.* – My sincere thanks are due to you for the explanation of this phenomenon. I have to search the Shastras to find out if any ceremonies are prescribed to be performed on the occasion; and what is more important to me, I have to provide myself with a telescope to observe this most interesting sight. I shall see you once more before I leave this for my native town. Good bye for the present.

EXPLANATION OF DIAGRAMS.

Fig. 1.– Shows the orbits of four of the primary planets round the Sun; S being the Sun, a the orbit of Mercury, b that of Venus, c of the Earth, and d of Mars (Vide para.12)

Fig. 2.– Represents the phases of Venus in the course of her motion around the Sun; that is, her apparent size and illuminated portion, as seen from Earth E at difference points in her orbit (Vide para.12)

Fig. 3.– Represents Eclipses of the Sun caused by Venus. Within conical shadow the Sun will be more than covered, as shown at a. Just at the end of the shadow, 600,000 miles beyond Venus, the eclipse will be exactly total, but only momentary, as at b. Shortly beyond that distance only an annular eclipse will be seen at c, and on receding from the Sun less and less of her disc will be observed as at d, c, f and g. Seen from the Earth, Venus will appear only as a dark spot on the Sun's disc as shown in h of the figure (Vide para.18)

Fig. 4.– Shows the path and position of Venus, when crossing the Sun's disc during its transit on the 9th December 1874. N. W. S and E. mark the cardinal points

of the Sun's disc; the arrow-headed line K L. traces the path of Venus across the Sun's disc; a and c are positions of ingress and egress respectively; and b the point when Venus will be nearest the Sun's centre, i.e., at the middle of the transit. (Vide paras.26 and 50)

Fig. 5.– The different forms that Venus will present both at ingress and egress as seen through a telescope. (Vide para.26)

Fig. 6.– Diagram illustrating the explanation of Parallax. (Vide para.40)

Fig. 7.– Also illustrates the explanation of parallax of terrestrial objects; 1, 2, 3, 4, 5 are balls which are at equal distances strung together in a horizontal line. When a person at A sees through the line he will refer all the balls to the point C, but if he sees them from the point B, he will refer them to, a, b, d, c and f respectively. This change in the apparent positions of the balls, is caused by the displacement of the spectator from A to B, and constitutes what is known technically as parallax.

Fig. 8.– For explanation see para.41

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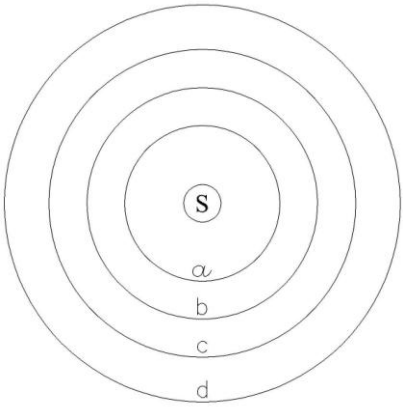

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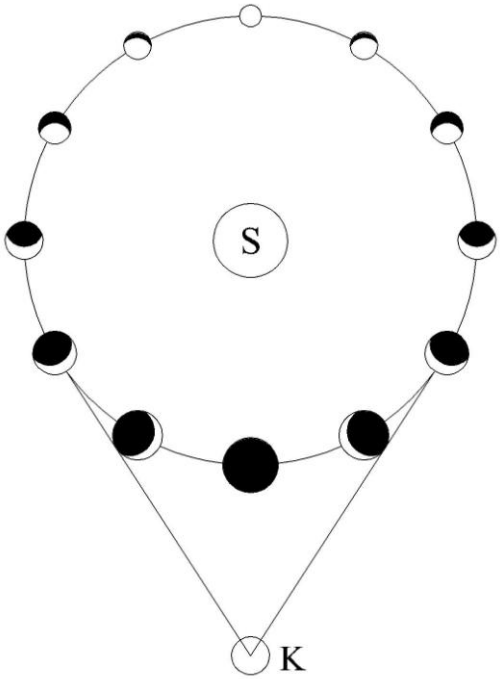

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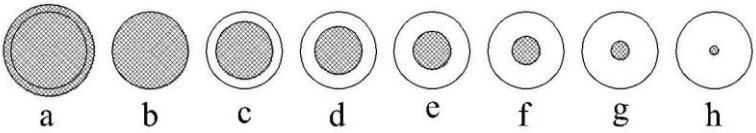

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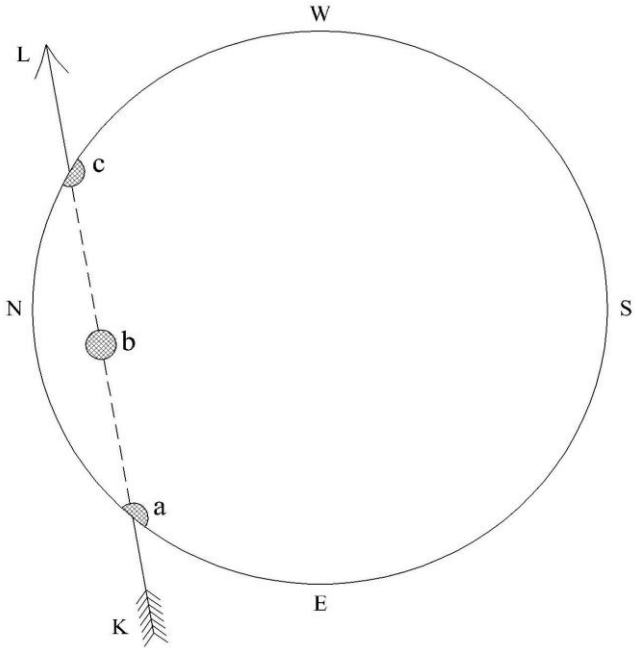

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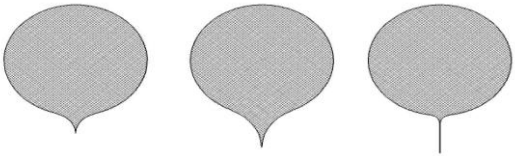

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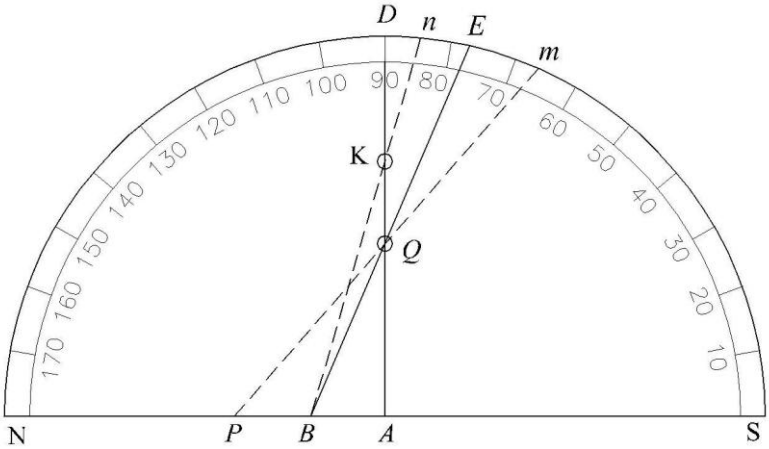
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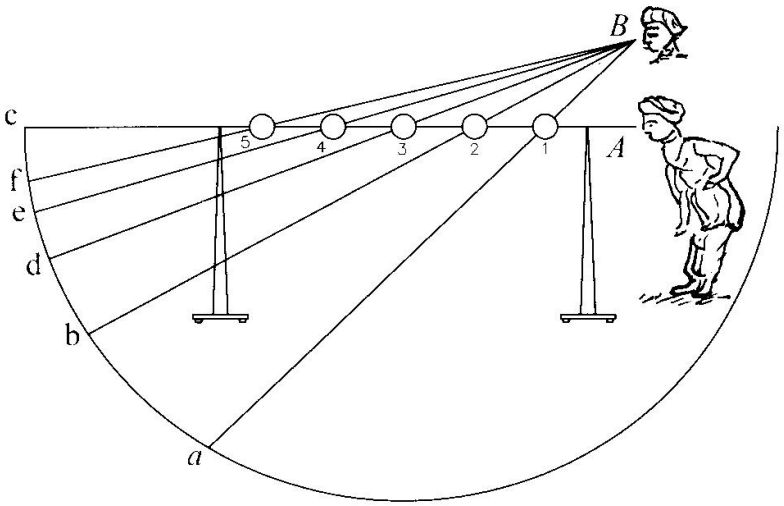
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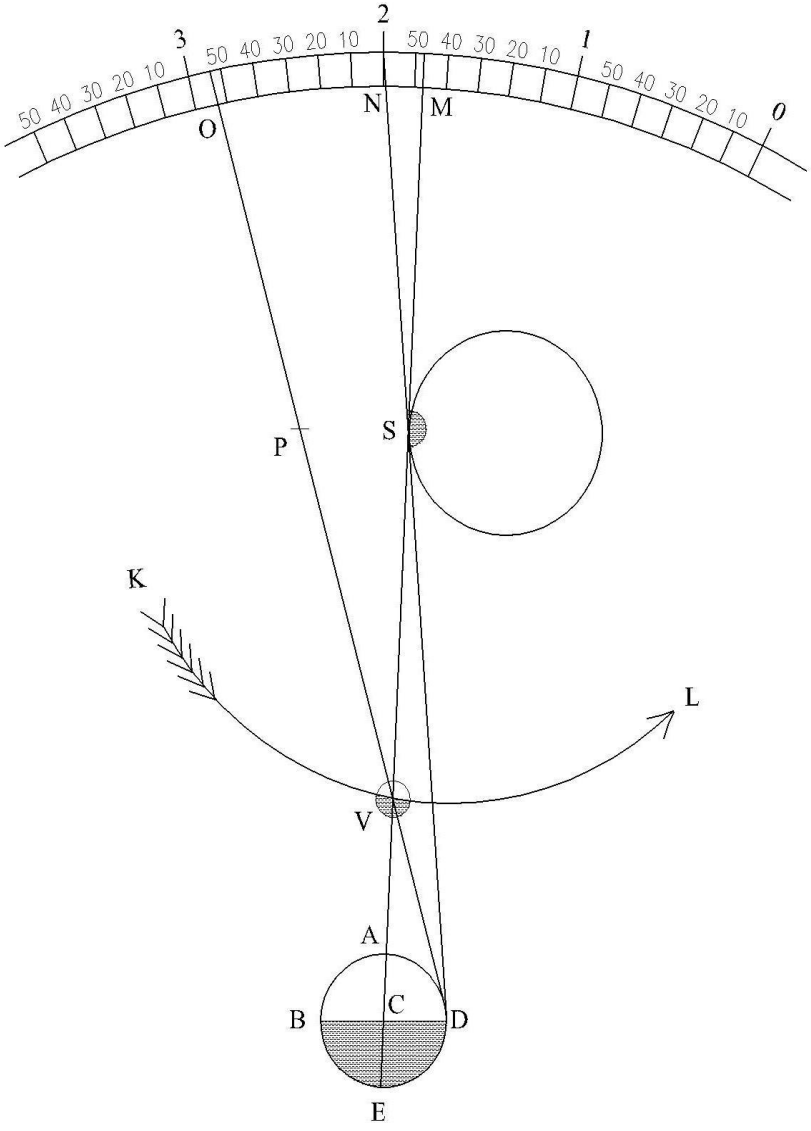

APPENDIX

Table showing the Local Mean Times &c., of the Solar Eclipses occurring on the 10th October, 1874, and on the 6th April 1875, for the few following chief Places in India

No.	Solar Eclipse of 10th October 1874				Solar Eclipse of 6th April 1875				
	Places.	Beginning of Eclipse	Shadow Length of a 12 Inch Rod at Beginning	Setting of the Eclipsed Sun	Beginning of Eclipse	Shadow Length of a 12 Inch Rod at Beginning	End of Eclipse	Shadow Length of a 12 Inch Rod at Ending	Magnitude of Eclipse Sun's Diameter - 1
		h. m.	Inches	*h. m.*	*h. m.*	Inches	*h. m.*	Inches	Decimal
1.	Agra	4. 18	41	5. 33	11.34	4.8	1. 20	6.3	0.24
2.	Bangalore	4. 52	57	5. 41	10.47	4.3	1. 17	4.2	0.55
3.	Bellary	4. 43	50	5. 40	10.49	4.4	1. 14	4.3	0.49
4.	Banares	4. 46	63	5. 34	11.46	4.2	1. 56	7.8	0.40
5.	Bhopaul	4. 25	42	5. 36	11.18	4.3	1. 18	5.5	0.33
6.	Bombay	4. 13	64	5. 38	10.45	5.0	0. 45	3.5	0.31
7.	Calcutta	5. 16	150	5. 36	12. 4	3.5	2. 31	9.8	0.57
8.	Calicut	4. 48	51	5. 42	10.33	5.0	1. 3	3.4	0.54
9.	Cashmere	3. 47	33	5. 20	12. 2	6.3	0. 32	6.5	0.02
10.	Columbo	5. 19	111	5. 44	10.41	4.5	1. 25	4.5	0.74
11.	Guntur	4. 56	66	5. 39	11. 8	3.6	1. 38	5.7	0.54
12.	Hyderabad	4. 44	55	5. 39	11. 4	3.9	1. 26	5.1	0.47
13.	Indore	4. 19	38	5. 36	11. 9	4.5	1. 7	4.9	0.30
14.	Lucknow	4. 33	52	5. 34	11.45	4.6	1. 41	7.2	0.31
15.	Madras	5. 2	73	5. 41	11. 0	3.6	1. 35	5.2	0.60
16.	Nagpore	4. 38	50	5. 37	11.19	3.9	1. 31	5.8	0.11
17.	Rajahmundry	4. 59	75	5. 39	11.18	3.5	1. 47	6.4	0.55
18.	Tanjore	6. 4	74	5. 42	10.47	4.1	1. 25	4.6	0.64
19.	Trevendrum	6. 1	66	5. 43	10.31	6.1	1. 9	3.3	0.61
20.	Vizyanagarum	5. 5	87	5. 38	11.29	3.1	1. 58	7.1	0.57

The first contact will take place in India generally at about 105 degree to the Right from the Vertex of the Sun's limb. The magnitude of the eclipse will vary from 0.38 to 0.78 (the Sun's diameter being I,) for places between Colombo and Cashmere

The first contact will occur between Colombo and Agra from 100 to 170 degrees to the Right from the sun's Vertex: and the last contact 50^0 from the Vertex to the Left. This eclipse will be total and its central line will pass through the Nicobar Island, Siam and Anam

OCCULTATIONS AND CONJUNCTIONS.

At noon, on Thursday the 12th November 1874, Venus will be seen to disappear behind the Moon's northern limb by spectators in the southernmost part of India, and to approach nearby these in Northern part. Although this phenomenon occurs at middle, still it will be visible to the naked eye, as it happens only a few days after Venus has attained her greatest brilliancy, and as she will be about 35^0 to the east of the Sun, the crescent Moon will also be seen just to the south of Venus. At Mangalore, Mysore, Salem, Trichinopoly, Tanjore and Negapatam, Venus will be seen either passing behind or gliding along the Moon's north limb: and to places south of the above mentioned Towns, she will be actually occulted; while to those in the North, she will appear very close to the Moon's limb. The times of disappearance and reappearance are given below for the following places:--

		A. m		*A. m*
Trevendrum ...	Disappearance	11.32	Reappearance	0.23
Cochin ...	do.	11.32	do.	0.17
Madura ...	do.	11.49	do.	0.11

On Wednesday the 16th December 1874 a close conjunction of Mars with Jupiter will occur. At 5 A.M. this day Mars will be situated 5' North 3' East of Jupiter.

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