ART. X.—*On the mode of observing the coming Transits of Venus;* by SIMON NEWCOMB.*

Transits of Venus over the disk of the sun have more than any other celestial phenomena occupied the attention and called forth the energies of the astronomical world. In the last century they furnished the only means known of learning the distance of the sun with an approach to accuracy, and were therefore looked for with an interest corresponding to the importance of this element. Although other methods of arriving at this knowledge with about equal accuracy are now known, the rarity of the phenomenon in question insures for it an amount of attention which no other system of observation can command. As the rival method, that of observations of Mars at favorable times, requires, equally with this, the general coöperation of astronomers, the power of securing this coöperation does in itself give the transits of Venus an advantage they would not otherwise possess.

Although the next transit does not occur for four years, the preliminary arrangements for its observation are already being made by the governments and scientific organizations of Europe. It is not likely that our government will be backward in furnishing the means to enable its astronomers to take part in this work. The principal dangers are, I apprehened, those of setting out with insufficient preparation, with unmatured plans

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of observation, and without a good system of coöperation among the several parties. For this reason I beg leave to call the attention of the Academy to a discussion of the measures by which we may hope for an accurate result.

In planning determinations of the solar parallax from the transits of Venus, it has until lately been the custom to depend entirely upon observations of the internal contact of the limbs of the sun and planet, as proposed by Halley. It is a little remarkable that while astronomical observations in general have attained a degree of accuracy wholly unthought of in the time of Halley, this particular observation has never been made with a precision at all approaching that which Halley believed that he himself had actually attained. In his paper he states that he was sure of the time of the internal contact of Mercury and and the sun within a second.* The latest observations of a transit of Mercury, made in November, 1868, are, as we shall presently see, uncertain by several seconds. It is also well known that the observations of the last transit of Venus, that of June, 1769, failed to fix the solar parallax with the certainty which was looked for, the result of the standard discussion being now known to be erroneous by one-thirtieth of its entire amount.

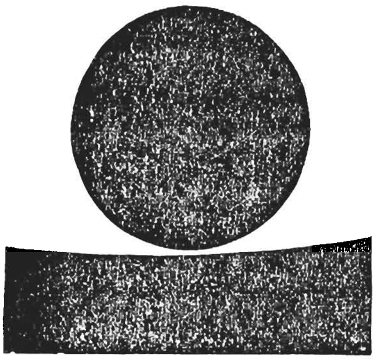
The discrepancies which have always been found in the class of observations referred to, when the results of different observers have been compared, have been generally attributed to the effect of irradiation. The phenomenon of irradiation presents itself in this form: When we view a bright body, projected upon a dark ground, the apparent contour of the bright body projects beyond its actual contour. It may be generalized as follows:—A lucid point, however viewed, presents itself to the sense, not as a mathematical point, but as a disc of appreciable extent, and, usually, of irregular outline. But, for our present purposes the form of the disc may be considered circular. Its outline is necessarily quite indefinite, and its magnitude increases with the brilliancy of the point. A bright body, being composed of an infinity of lucid points, its apparent enlargement is an evident result of this law.

The following diagrams show the effect of this law upon the time of internal contact of a planet with the disk of the sun. The planet being supposed to approach the solar disk, figure 1 shows the geometrical form of a portion of the apparent surface of the sun, or the phenomenon as it would be if there were no irradiation immediately before the moment of internal contact. Figure 2 shows the corresponding appearance immediately after the contact. To indicate the effect of irradiation, or to show the phenomenon as it will actually appear on the theory of irra-

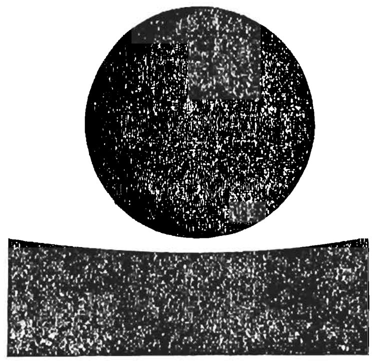
* Philosophical Transactions, No. 348, p. 454.

diation, we have only to draw an infinity of minute circles, one from each point of the sun's disk visible around the planet.

1.

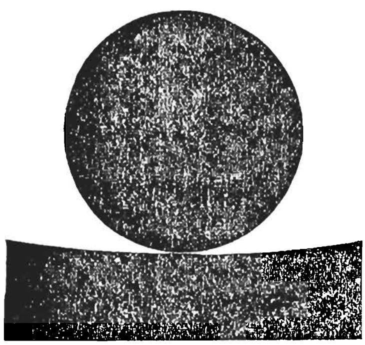


1*a*.

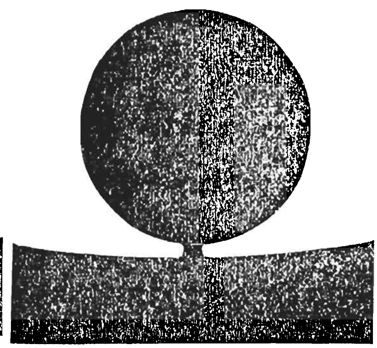


The effect of this is shown in the figures 1*a* and 2*a*. The exceedingly thin thread shown in figure 1 is thus thickened as

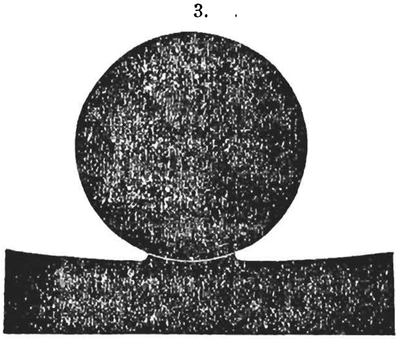
2.



2*a*.



3.



in 1*a*, and the sharp cusps of figure 2 are rounded off as shown in figure 2*a*. The apparent radius of the planet is diminished by an amount equal to the radius of the circle of irradiation, and the radius of the sun is increased by the same amount. Comparing figures 1*a* and 2*a*, it will be seen that the moment of internal contact is marked by the apparent formation of a ligament, or "black drop," between the limbs of the sun and the planet. This formation is of so marked a character that it

has been generally supposed there could be little doubt of the moment of its occurrence. The remarks of the observers have given color to this supposition, the black drop being generally described as appearing suddenly at a definite moment.

Examining figure 2*a*, it will be seen that the planet still appears entirely within the disk of the sun. The geometrical circle which bounds the latter, and that which bounds the planet, instead of touching, are separated by an amount equal to double the irradiation. If the observer waits until the planet has moved over this space, the two circles will appear in that position in which they would touch if completed. This phase commonly called "apparent contact," is shown in fig. 3. Neither circle is visible at the point of tangency, the black drop, now greatly widened and flattened, extending on both sides this point. The estimate of the moment of contact must therefore be very rough, the means of estimating being far less accurate than those afforded by a common filar micrometer. In the actual case the eye has to continue the two circles to the point of contact by estimation through a distance depending on the amount of irradiation, while measures with a micrometer are made by actual contact of a wire with a disk. Such estimates have, therefore, been generally rejected by investigators, not only from their necessary inaccuracy, but because the time of "apparent contact" depends upon the amount of irradiation, which varies with the observer and the telescope. If there is no irradiation at all, the time of apparent contact and that of true contact will be the same, as shown in figure 2; while, when the cusps are enlarged by irradiation, apparent contact will not occur until the planet has moved through a space equal to double the irradiation.

Let us return to the phenomena at actual contact. According to the theory as it has been presented, the formation or rupture of the black ligament connecting the dark body of Venus with the dark ground of the sky is a well-marked phenomenon, occurring at the moment of true internal contact. This was, I believe, the received theory until Wolf and André made their experiments on artificial transits in the autumn and winter of 1868 and 1869. They announced, as a result of these experiments, that the formation of the ligament was not cotemporaneous with the occurence of internal contact, but followed it at the ingress of the planet, and preceded it at egress. In other words, it appeared while the thread of light was still complete. They furthermore announced that with a good telescope the ligament did not appear at all, but the thread of light between Venus and the dark sky broke off by becoming indefinitely thin.

The result is not difficult to account for. Irradiation has already been described as a spreading of the light emitted from each point of the surface viewed, so that every such point appears as a small circle. The obvious effect of this spreading is a dilution of the light emitted by a luminous thread or point whenever the diameter of the thread is less than that of the circle of irradiation. In consequence of this dilution the thread may be invisible while it is really of sensible thickness, a given amount of light producing a greater effect on the eye the more it is concentrated. Since the thread of light must seem to break when it becomes invisible at its thinnest point, the formation or rupture of the thread marks, not the moment of actual contact, but the moment at which the thread of light becomes so thick as to be visible, or so thin as to be invisible. The greater the irradiation, and the worse the definition, the thicker will be the thread at this moment.

An interesting observation illustrative of this point was made by Liais at Rio Janeiro during the transit of Mercury of November 1, 1868. He had two telescopes, one much smaller than the other. He watched the planet in the small one till it seemed to touch the disk of the sun. Then looking into the large one he saw a thread of light distinctly between the planet and the sun, and they did not really touch until several seconds later.*

Reference to the figures will make it clear that there is no generic difference between the phenomenon commonly called the rupture of the black drop and that of the formation of the thread of light. If the bright cusps are much rounded, as in figure 2*a*, the appearance between them is necessarily that of a drop, while if they are seen in their true sharpness, as in figure 1, the form of the drop will not appear. It has been shown that with different instruments the phenomenon of contact may exhibit every gradation between these extremes. The only well defined phenomenon which all can see is the meeting of the bright cusps and the consequent formation of the thread of light at ingress and the rupture of the thread at egress.

To recapitulate our conclusions—

1. The moment of observed internal contact at ingress is that at which the thread of light between Venus and the sun becomes thick enough to be visible.

2. The least visible thickness varies with the observer and the instrument, and, perhaps, with the state of the atmosphere.

3. The apparent initial thickness of the thread varies with the irradiation of the telescope.

Two questions are now to be discussed. The observed times varying with the observer and the instrument, we must know how wide the variation may be. If it be wide enough to ren-

* Astronomische Nachrichten, B. 73, S. 209.

der uncertain the results of observation, we shall inquire how its injurious effects may be obviated.

The first question can be decided only by comparison of the observations of different observers upon one and the same phenomenon. For such comparison I shall select the observations of the egress of Mercury on the occasion of its last transit over the disk of the sun. This selection is made for the reason that this egress was observed by a great number of experienced observers with the best instruments, while former transits, whether of Venus or Mercury, have been observed less extensively or at a time when practical astronomy was far from its present state of perfection, and that the transit in question would therefore furnish much better data of judging what we might expect in future observations. The comparison was made in the following way: I selected from the "Astronomische Nachrichten," the "Monthly Notices of the Royal Astronomical Society," and the "Comptes Rendus" all the observations of internal contact at egress which there was reason to believe related to the breaking of the thread of light, and which were made at stations of known longitude. Each observation was then reduced to Greenwich time and to the center of the earth.

The results are exhibited in the following table. The third column of the table shows the corrected reduced times of contact. Next is given the aperture of the telescope, and the magnifying power employed in the observation. Lastly, we present a classification of the phenomena of contact as described by the observers.

The letters V. C., (vanishing contact,) indicate that the thread of light broke by becoming indefinitely thin, so that there was no irradiation or distortion of the planet.

The letters B. D. (black drop) indicate the appearance of the ligament, as shown in fig. 2*a*.

R. R. Indicates that the time is that of the rupture of the thread, but that it cannot be inferred from the statements of the observer whether the thread had or had not a sensible thickness immediately before breaking.

A. C. Signifies an apparent contact, as shown in fig. 3. When there is no black drop the letters V. C. and A. C. have the same meaning. The letters are therefore employed only when there is reason to believe from the remarks of the observer that the cusps were rounded.

(Inst.) indicates that the observer described the phenomenon as instantaneous.

The letters *b* and *g* refer to the definition, the first indicating that it was bad, the second that it was good.

When there is no indication in this column the observer gives no information respecting the phenomenon.

Observer.	Place.	Reduced Time of Int. Contact.	Aper-ture.	Power.	Character of Phenomenon.
		h. m. s.			
Oppolzer,*	Vienna,	20 59 49·3	4	--	B. D. b.
Oppenheim,	Bonn,	51·8	--	--	b.
Rayet,	Paris,	57·0	5·5	222	V. C.
Le Verrier,†	Marseilles,	57·6	--	--	B. D. (Inst.) g.
Lynn,	Greenwich,	59·2	?	170	B. D.
P. J. Kaiser,	Leiden,	59·2	3	--	R. R. (?) b.
Wolff,	Bonn.,	21 0 1·3	--	--	b.
Liais,‡	Atalaïa,	1·5	--	78	V. C. (g.)
Rosen,	Pulkowa,	2·7	5	59	
Stone,§	Greenwich,	4·0	12¾	245	B. D.
Lais,	Rome,	4·6	2	40	R. R.
Kartazzi,	Pulkowa,	4·7	2·9	145	
Wagner,	"	4·7	3·7	148	
Nyren,	"	4·7	7·4	57	
Fuss,	"	4·7	2·4	63	
Dunkin,‖	Greenwich,	4·7	3·7	300	B. D.
André,	Paris,	4·9	5	188	V. C.
Argelander,	Bonn,	5·3	--	--	b.
Oppolzer,	Vienna,	6·3	4	--	A. C.
Dr. Peters,	Altona,	7·3	4	111	b.
Villarceau,	Paris,	8·3	7·3	163	V. C.
Lebedeff,	Pulkowa,	8·7	2·2	70	
Dollen,	"	8·7	2·2	81	
Miroschnit schenko,	"	8·7	3·7	106	
Leskinen,	"	8·7	3·9	117	
Mancini,¶	Rome,	9·5	6	60	R. R.
H. J. Carpenter,	Greenwich,	9·6	?	70	R. R.
Kasavinoff,	Pulkowa,	10·7	1·1	36	
Kaiser,	Leiden,	10·8	7		B. D. b.
Criswick,**	Greenwich,	11·3	4?	170	B. D.
Wolf,	Paris,	11·4	8	200	V. C.
Secchi,	Rome,	11·5	7	200	R. R.
J. Carpenter,	Greenwich,	12·6	3·7	90	B. D. (Inst.)
Prof. Peters,	Altona,	13·3	3	145	b.
Weiss,	Vienna,	13·3	5	40	b.
Struve,	Pulkowa,	13·7	2·5	207	R. R.
Stephan,	Marseilles,	13·7	--	--	R. R. (Inst.)
Merino,	Madrid,	14·1	5	100	R. R. g.
Duner,	Lund,	14·2	9	320	V. C. g.
Stone,	Greenwich,	16·0	--	--	A. C.
Buckingham,	Walworth,	17·3	--	--	B. D.
Sokolov,	Pulkowa,	18·7	2·8	226	
Kam,	Leiden,	19·0	6	--	R. R. (?) b.

* "8s vor dem Brechen des Lichtfadens schien Mercur gleichsam den Sonnenrand etwas hinauszuchieben so dass an der Stelle des Austrittes ein nach aussen convexer Lichtfaden den Mercur umschloss und dessen Verschwinden ich als den Moment der inneren Berührung notirte."

† Le Verrier used a seven-inch glass with a diaphragm over the objective.

‡ Three seconds before this time the contact was not completed, and three seconds later it was more than completed.

§ A fine ligament seen several seconds before the time recorded.

‖ The planet was suddenly noticed to assume a balloon or pear shape. The apparent contact about 10^s later.

¶ Observed by image in camera obscura, 22 c. m. in diameter.

** Instantaneous. Time perhaps 2^s or 3^s late.

TABLE—continued.

Observer.	Place.	Reduced Time of Int. Contact.	Aper-ture.	Power.	Character of Phenomenon.
		h. m. s.			
Ventosa,*	Madrid,	21·0	1·0	150	B. D. (Inst.)
Kaiser,	Leiden,	23·8	7	--	A. C. b.
Lindeman,	Pulkowa,	24·7	4·2	85	
Prince,	Uckfield,	28·5	--	--	A. C. (?)
Pohl,	Kahlenberg,	29·6	4	135	V. C.
Lynn,†	Greenwich,	31·1	?	170	A. C.
Penrose,	Wimbledon,	52·2	2·2	70	R. R.

In the preparation of this table, the original intention was to exclude all observations unaccompanied with any statement of the phenomena. An exception was afterward made in favor of the observations of Bonn and Pulkowa, so that in this respect there is a lack of homogeneousness in the table. The few observations of "apparent contact," have also been added, in the belief that they would not be devoid of interest.

The principal conclusion, to be drawn from the comparison here exhibited, is that there is no discoverable relation between the time of observation on the one hand, and the size of the telescope, the magnifying power, (so it exceed 50 or 60) or the character of the phenomenon on the other. We find the phenomenon of the apparently instantaneous formation of the "black drop" to range from $20^h\ 59^m\ 58^s$ (Le Verrier) to $21^h\ 0^m\ 21^s{\cdot}0$ (Ventosa). The times of "Vanishing Contact" on which Wolf and André lay so much stress, range from $20^h\ 59^m\ 57^s$ to $21^h\ 0^m\ 29^s$. If we reject Pohl's observation, the range will still be 17^s. I think if the observations of external contact were collected and compared in the same way, it would be found that their agreement was as good as in the case of internal contact. So far as we have data for judging, these differences would seem to be due to the accidental errors of observation. Their amount in arc may be inferred from the fact that 15^s of time correspond to a change of $1''$ in the relative position of Mercury and the sun.

I conceive, therefore, that we shall fail if we rely mainly on observations of internal contact. Still, there are two measures by which the reliableness of the determination of ingress and egress may be greatly increased. The first consists in having the observer occupy the entire time of partial ingress and egress in making very careful measures of the distance of cusps with such micrometer as may be best adapted for the purpose. The second consists in bringing the observers at opposite stations together, both before and after the transit, and causing them to make observations on artificial transits with the same instru-

* Contact seemed to be established simultaneously at several points.

† Doubtful. Limbs "certainly in contact by at least that time."

ments employed in observing the transit of Venus, in order to determine what correction should be applied to the observations of one to make them comparable with those of the other. It would be a comparatively simple operation to erect an artificial representation of the sun's disk at the distance of a few hundred yards, and to have an artificial planet moved over it by clockwork. The actual time of contact could be determined by electricity, and the relative positions of the planet and the disk by actual measurement. With this apparatus it would be easy to determine the personal errors to which each observer was liable, and these errors would approximately represent those of the observations of actual transit.

Still, it would be very unsafe to trust entirely to any determination of ingress or egress. Understanding the uncertainty of such determinations, the German astronomers have proposed to trust to measures with a heliometer, made while the planet is crossing the disk. The use of a sufficient number of heliometers would be both difficult and expensive, and I think we have an entirely satisfactory substitute in photography. Indeed, Mr. De la Rue has proposed to determine the moment of internal contact by photography. But the result would be subject to the same uncertainty which affects optical observations—the photograph which first shows contact will not be that taken when the thread of light between Venus and the sun's disk was first completed, but the first taken after it became thick enough to affect the plate, and this thickness is more variable and uncertain than the thickness necessary to affect the eye. We know very well that a haziness of the sky which very slightly diminishes the apparent brilliancy of the sun, will very materially cut off the actinic rays, and the photographic plate has not the power of adjustment which the eye has.

But, although we cannot determine contacts by photography, I conceive that we may thereby be able to measure the distance of the centers of Venus and the sun with great accuracy. Having a photograph of the sun with Venus on its disk, we can, with a suitable micrometer, fix the position of the center of each body with great precision. We can then measure the distance of the centers in inches with corresponding precision. All we then want is the value in arc of an inch on the photograph plate. This determination is not without difficulty. It will not do to trust the measured diameters of the images of the sun, because they are affected by irradiation, just as the optical image is. If the plates were nearly of the same size, and the ratio of the diameters of Venus and the sun the same in both plates, it would be safe to assume that they were equally affected by irradiation. But should any difference show itself, it would not be safe to assume that the light of the sun encroached equally upon the dark ground of Venus and upon the sky, because it is so much fainter near the border.

If the photographic telescope were furnished with clock-work, it would be advisable to take several photographs of the Pleiades, both before and after the transit, to furnish an accurate standard of comparison free from the danger of systematic error. There is little doubt that if the telescopes and operators practice together, either before or after the transit, data may be obtained for a satisfactory solution of the problem in question.

To attain the object of the present paper, it is not necessary to enter into details respecting choice of stations and plans of observation. I have endeavored to show that no valuable result is to be expected from hastily-organized and hurriedly-equipped expeditions; that every step in planning the observations requires careful consideration, and that in all the preparatory arrangements we should make haste very slowly. I make this presentation with the hope that the Academy will take such action in the matter as may seem proper and desirable.