PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

# On the Determination of the Photometric Intensity of the Coronal Light during the Solar Eclipse of August 28-29, 1886

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# ERRATA.

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Page 376, line 4 from bottom, *for* solar diameter *read* solar semi-diameter.

Page 381, line 24, *for* 200 *read* 100.

Page 381, line 26, *for* $\frac{1}{800}$ *read* $\frac{1}{80}$.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

# XI. *On the Determination of the Photometric Intensity of the Coronal Light during the Solar Eclipse of August* 28–29, 1886.

*By Captain* W. DE W. ABNEY, *C.B., R.E., F.R.S., and* T. E. THORPE, *Ph.D., F.R.S.*

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## *Introduction.*

ALTHOUGH it has long been suspected that the amount of light emitted by the corona, as seen at various Solar Eclipses, may vary within comparatively wide limits, no attempts to measure its intensity appear to have been made prior to the Eclipse of December 22, 1870. On that occasion Professor PICKERING employed an arrangement constructed on the principle of BUNSEN's photometer. It consisted of a box 9 inches wide, 18 inches high, and 6 feet long, within which a standard candle could be moved backwards and forwards by means of a rod. One end of the box was covered with a piece of thin white paper, on which was a greased spot about half an inch in diameter. The box was adjusted so that the rays from the corona were normal to the plane of the paper, and the lighted candle was moved backwards and forwards within the box until the grease-spot was no longer visible. From a number of observations made during the period of totality of this eclipse, Mr. WALDO O. ROSS, acting under Mr. PICKERING's direction, found that the standard candle had to be placed at distances varying from 14·4 to 21 inches from the paper before the visibility of the greased spot was reduced to a minimum. ('U.S. Coast Survey Reports,' 1870, p. 172.) The observations were much interrupted by clouds, and are also probably affected by irregularities in the rate of the burning of the candle. The mean of all the readings was 18·5 inches: hence the light of the corona in 1870 was apparently equal to 0·42 of a standard candle at a distance of 1 foot.

A precisely similar arrangement was used by Dr. J. C. SMITH during the Solar Eclipse of July 29, 1878. Dr. SMITH, observing at Virginia City, Montana, U.S., found from eight observations that the candle had to be placed at a distance of $51\frac{1}{4}$ inches from the screen before the minimum of visibility of the greased spot was obtained.

During the same eclipse, Professor JOHN W. LANGLEY made observations on the intensity of the coronal light as seen from the summit of Pike's Peak, Colorado, by means of a photometric arrangement suggested by Professor S. P. LANGLEY, and intended to measure the relative distribution of light in the corona. The idea was, first, to draw an outline of the corona; second, to measure the light of the corona at several points along a solar radius extended to the outer limits of visibility; and third, to draw one or more iso-photal lines which should give the contour of the corona for varying degrees of illuminating power. The method was to project the image of the corona upon the screen of a BUNSEN'S photometer in which glass ground to slight opacity replaced the greased paper; and instead of one translucent spot there was a large number, in order that several hundred samples of coronal light taken from different portions of its surface might be observed simultaneously, and compared with the standard light by drawing iso-photal contour lines.

In the apparatus as finally arranged the screen consisted of a piece of perforated cardboard covered by a sheet of oiled paper. A number of translucent spots separated by opaque interspaces was thus obtained, the spots being sufficiently close together to allow the projected image to be seen with but little loss of distinctness. The light from the corona was reflected from a heliostat and transmitted through a photographic lens of long focus, the aperture of which could be diminished, if required, by means of a cat's-eye diaphragm, and passed down a dark chamber about 41 feet in length, at the end of which was a box carrying the screen and standard candles. Within the box was a railway, on which ran a wagon mounted on brass wheels and bearing the lighted candle, the distance of which from the screen was recorded on a wooden rod placed immediately in front of the observer. The whole apparatus stood on four piers, and it was so arranged that any vibration caused by wind should not be communicated to the lens producing the coronal image. The focal length of the lens was 11·27 metres; and the diameter of the solar focal image was ·104 metre.

The corona as actually observed was excessively faint, and could only be seen to an extent of less than 1′ from the Moon's edge. The coronal light was so feeble that it was found impossible to measure its intensity at several points along an extended radius.

From his observations Professor LANGLEY concludes that the light from the corona at 1′ from the limb of the Moon was equal to that of the standard candle at a distance of 1 metre. From the photometric value of the candle as compared with diffused sunlight, LANGLEY further found that the intensity of the coronal light about 1′ from the limb of the Moon was ·0000132 of that of mean sunlight; at 3′ from the limb it was ·0000000244. Assuming the intensity of mean sunlight to be 500,000 times greater than that of moonlight, the corona at 1′ from the Moon's limb was six times the intrinsic brightness of the Moon; at 3′ it was but one-tenth the intrinsic brightness of the Moon. (Professor S. P. LANGLEY'S Report, p. 211, 'Washington Observations' for 1876, Appendix III.)

The photometric observations made during the 1878 Eclipse have also been discussed by Professor W. HARKNESS, of the United States Naval Observatory (*loc. cit.*, p. 386). Combining the observations, he concludes that the total light of the corona was ·072 of that of a standard candle at 1 foot distance, or 3·8 times that of the full Moon, or ·0000069 of that of the Sun. It further appears from the photographs that the coronal light varied inversely as the square of the distance from the Sun's limb.

Probably the brightest part of the corona was about 15 times brighter than the surface of the full Moon, or 37,000 times fainter than the surface of the Sun.

It would further seem that the corona of December 22, 1870, was $7\frac{1}{4}$ times brighter than that of July 29, 1878.

### *Description of Methods Adopted during the Eclipse of August* 28–29, 1886.

The instruments used by us for the measurement of the coronal light on this occasion were three in number. The first was constructed to measure the comparative brightness of the corona at different distances from the Moon's limb. The second was designed to measure the total brightness of the corona, excluding as far as possible the sky effect. The third was intended to measure the brightness of the corona, together with the brightness of the sky in the direction of the eclipsed Sun.

In a paper by one of us, in conjunction with General FESTING,* it was shown that light of any colour can be measured for luminosity in terms of light of any other colour, provided always that the last-named light can be rapidly altered in intensity, so that at one time it is evidently below the intensity of the light to be compared, and immediately afterwards that it is evidently above it. The oscillations of the intensity, if then gradually diminished, finally give the value of the coloured light in terms of the luminosity of the light of which the intensity is rapidly changed.

In a more recent paper† it has been shown that the light of a glow lamp may be used for measuring the intensity of any other light by making a rapid change in the resistance of the circuit. In the photometric measures which are now to be described this plan was adopted for ascertaining the value of the coronal light in terms of a Siemens unit. Before continuing the description it may be well to note that the Siemens unit is very nearly 0·8 of a standard candle. This unit has the advantages that the area of the burner is fixed; that the flame used in the photometric measures can always be made of exactly the same height; that the thickness and shape of the flame are practically invariable; that the material producing the flame can be obtained in commerce; and that any slight impurity in it has no practical effect on the value of the light emitted. Neither the effect of the temperature at the time of trial nor the variation due to difference in barometric pressure has been thoroughly tested, but there are presumably but slight differences due to these causes. At all events, there is nothing to prevent its employment for the object we had in view. One experiment may, however, be quoted as regards the luminosity of the flame when the temperature was varied some 20°. The lamp was carefully adjusted so that the tip of the flame just touched the gauge supplied with the instrument, and its value taken against the glow lamp, which was kept at a bright yellow heat by a current passing through it. A large photograph of the flame was also taken. The

* 'Phil. Trans.,' 1886, "Colour Photometry," ABNEY and FESTING.

† 'Roy. Soc. Proc.,' vol. 43, 1887, ABNEY and FESTING.

lamp was then warmed from 55° to 75°; the flame became longer, but when turned down to the height of the gauge the same value was obtained against the glow lamp as before within 2 per cent. Another photograph was taken of the flame from the same position, and the two compared. The flames in both cases were equal in dimensions.

In the paper last referred to it was also shown that either the Bunsen or the Rumford method of photometry could be adopted. The method of Rumford is undoubtedly better than that of Bunsen when the lights are very different in colour, as in the latter method there is a certain thickness of translucent material through which both lights have to pass, and only after such passage can equality of illumination be estimated; and if the paper employed for the screen is coloured in any degree, this must of necessity affect the results. The light of the corona and that of the glow lamp are very different in colour, the former being stronger in the blue end of the spectrum than the latter. It must be recollected that the greatest luminosity is in the yellow of the spectrum in both cases, and, though the blue end of the spectrum alters the hue, it has very small effect on the luminosity. This being the case, it was thought that no error of any magnitude would be introduced by adopting the Bunsen plan, since the brightest part of the two spectra would be compared with one another.

It was evidently impracticable to adopt the Rumford method in the apparatus in which the intensity of different points in the corona had to be measured. For this purpose a telescope by Simms, lent by the Astronomer Royal, was employed. The object glass had a focal length of 78 inches and an aperture of 6 inches, thus forming an image of the Moon ·76 inch in diameter. The image was received on a circular white screen contained in a photometric box and placed exactly in the focus of the object glass. In the centre of the screen was traced a circle of the diameter of the image of the Moon, and during the observation the Moon's disc was made to fall exactly within the circle. As the telescope was equatorially mounted with clock-work, the image was kept stationary within the circle. The screen was of Rives' paper of medium thickness, and round the pencil-circle a series of small grease spots about $\frac{1}{8}$ of an inch in diameter had been made. There was some difficulty in preparing these small grease spots, but a method was eventually devised which answered admirably. Faint pencil lines were drawn radially from the centre of the circle, and the places where each spot was to be produced were marked with a dot. White blotting paper was soaked in spermaceti, any excess being avoided. Small discs, $\frac{1}{8}$ inch, were punched out, and these discs were put centrally on the dots. Blotting paper was next placed over them when in position, and a hot flat-iron was passed over them. The blotting paper and the small discs were then removed, and clean blotting paper and the flat-iron again applied to remove any slight excess of spermaceti. The screen now presented the appearance shown in fig. 1.

Several screens were made and tested. The test consisted in causing a glow lamp on one side of the screen to balance a glow lamp placed at the same distance on the other side by means of a variable resistance in the circuit. The spots, if correctly made, become invisible at the same time. The majority of screens fulfilled this condition, and the best as regards uniformity of size of spot and freedom from grain in the paper were selected for use. The screen, as will be seen from the figure, was mounted in a circular frame, which could be rotated so as to bring the spots into any desired angular position. It could be removed at pleasure by releasing it from the buttons which held it in position.

Fig. 1.

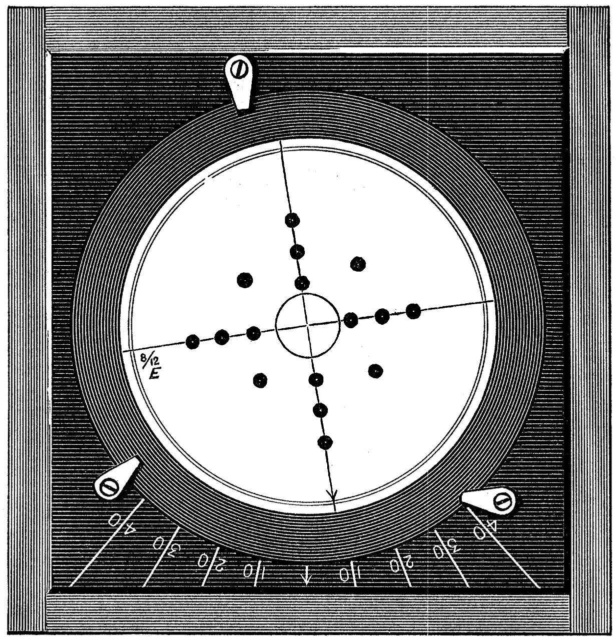
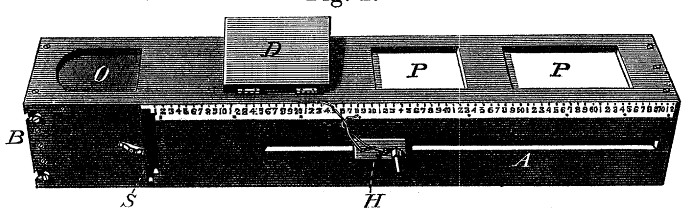


Fig. 2.




To hold the screen a box was constructed, as shown in fig. 2. It was made as light as possible, panels of card (as at P, P) being used instead of wood when practicable. The glow lamp to be employed was fixed in a holder inside the box; this could move along the slot A, and be fixed by a thumbscrew, H, in any desired position. (It may here be remarked that the plane of the filament was at right angles to the axis of the tube.)

At the end B was an aperture into which the sliding tube of the telescope fitted; at D was a door, which could be opened to adjust the lamp. The screen shown in fig. 1 was inserted at S, and held in position by means of buttons. At O was an opening, which was covered by a black velvet bag into which the head of the observer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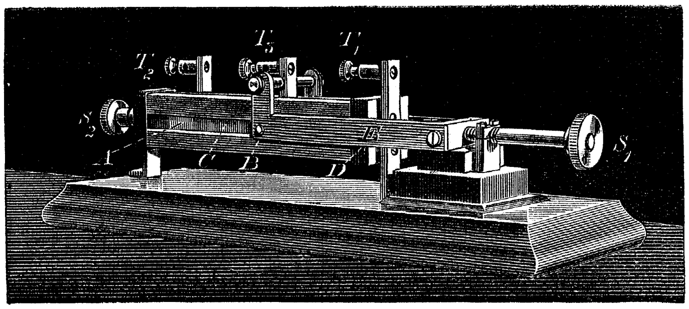
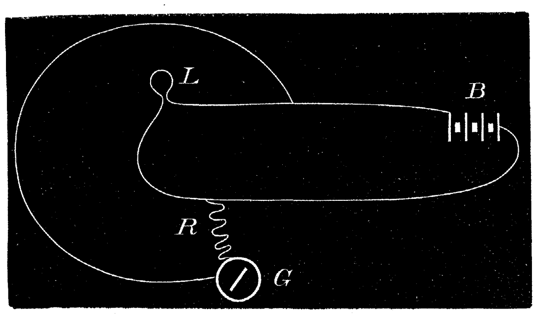
was inserted during the time of observation. As before said, the image of the Moon was accurately focussed on the screen inserted at S, and was viewed through the opening at O. The wires to the lamp passed through the slot; the carbon-resistance (fig. 3) and also the galvanometer should have been introduced into the circuit.

Fig. 3.



The carbon-resistance used was one supplied by Mr. VARLEY, and the description is taken from a paper already referred to. It consisted of a series of pieces of carbonised cloth, more or less in contact. The carbonised cloth is represented by C (fig. 3), which fills the whole length from A to D when loosely packed. At B is a plate to which $T_3$ is attached, and which can be separated more or less from a fixed metal plate to which $T_1$ is connected by the arm E, which is moved by the screw $S_1$. At A is an insulated block, carrying another plate to which $T_2$ is attached, and A can be carried backwards or forwards by means of the screw $S_2$. For some purposes the main current can be brought in at $T_3$, and leads be taken from $T_2$ and $T_1$, thus forming part of a Wheatstone bridge. During the eclipse the terminals $T_1$ and $T_3$ were used.

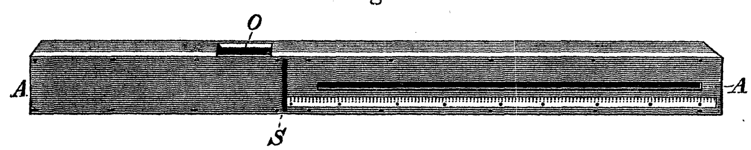
Fig. 4.




The connections were made as shown in fig. 4. The current from 10 cells of a carefully made up Grove battery, B, was passed through the lamp L. A shunt, including the galvanometer, G, and the resistance, R, was made. The brightness of the lamp was thus increased by adding more resistance to the shunt. Consequently, in the measures made, the highest readings of the galvanometer showed the lowest intensity of light. It would have been better had the ordinary plan of putting the galvanometer and resistance in the main circuit been adopted, but when once the value of the lamp illumination by the plan actually employed had been ascertained for varying resistances it became a matter of no moment. The galvanometer used in this case was one of THOMSON'S ammeters, made more sensitive by fixing a permanent magnet alongside the usual magnet, so as partially to neutralise its magnetism. By this plan a very small change in current gave a large deflection, or at all events a deflection which was readable. By reproducing these deflections under exactly similar conditions the illuminating value of the lamp could be measured in the ordinary way.

The second instrument, which we shall call the integrating box, for measuring the total coronal light with as little light from the sky as possible, was constructed on the same principles. It consisted merely of a long deal box coated internally with lamp-black, in which a screen with a large grease spot was inserted at S. There was a

Fig. 5.




similar slot for the lamp as in the other instrument. The end A was, however, open, and during the eclipse it was placed at such an angle that the axis of the tube pointed to the centre of the Moon. The aperture, O, for making the observations was in this case also covered with a black velvet cloth, under which the head of the observer was placed.

The third piece of apparatus consisted of an ordinary Bunsen bar photometer, 60 inches in length, with movable disc, made by Messrs. ALEX. WRIGHT and Co., of Westminster. As originally arranged, it was fitted for two standard candles; for the purpose of the eclipse observations, these were replaced by a small glow lamp.

As the plan of the photometric work contemplated by us depended for its execution upon such assistance as we were able to get out at Grenada, it was arranged that we should take advantage of the kind offer of service made by Captain ARCHER and the officers of H.M.S. "Fantôme," which had been told off to assist the expedition, and make the observations at some spot in convenient proximity to the anchorage of that vessel. As the latter end of August falls during the hurricane season in the West Indies, it was desirable to moor the "Fantôme" in the most secure anchorage in the island, viz., in Clerk's Court Bay, which is at the south end of Grenada. It appeared from the charts that a suitable station might be found on the southern end of Caliveny Island, distant about $1\frac{1}{2}$ mile from the spot which would be made use of as the anchorage. Caliveny Island was accordingly included in the list of stations provisionally selected by the Eclipse Committee of the Royal Society, and submitted to the Governor of Grenada. Mr. SENDALL and Captain HUGHES were kind enough to visit the spot, and they reported that a fairly good station might be obtained on the extreme end of the island, but that difficulties might be experienced in landing the apparatus. Captain ARCHER deemed it prudent, therefore, to make a preliminary survey of the place before the "Fantôme" left St. George. No landing was practicable on the leeward side of the island, and, although two or three places were met with on the other side, they could only be counted upon during fine weather. Moreover, as the greater part of the island is covered with dense "bush," the transport of the instruments to and from the station would be very laborious and tedious. There was the further difficulty that it was well nigh impossible to make one's way through the tangle of bush at night, when much of the work of adjustment of the equatorial would have to be done. And, lastly, there was the possibility, even if the instruments were successfully set up, that the noise of the surf and the driving spray in bad weather might seriously interfere with the work of observation.

For these reasons we decided to abandon the Caliveny site, and, after a careful examination of the neighbourhood, we selected a station near a little creek on Hog Island, to the westward of the bay. The position was fairly good; during dry weather it was indeed all that could be desired. The ground was about 10 to 15 feet above the sea level, and was close to a shelving, sandy beach, readily accessible and generally free from swell. In bad weather, another landing could be obtained round a point to the north, with only a few hundred yards of bush to be got through. The position had a good eastern horizon, the sun rising behind the lowland running out to Point Egmont, which here subtended an angle of less than 1°. Its position, as taken off the Admiralty Chart, was lat. 12° 0′ 4″ N., long. 61° 43′ 45″ W.

The "Fantôme" left St. George on the 17th August, and came into Clerk's Court Bay in the afternoon of the same day. All the apparatus was safely got to shore before nightfall, and the positions for the base of the equatorial and for the tents of the party undertaking the integrating work were decided upon. Early next morning the erection of the wooden hut to shelter the equatorial was begun, and a concrete base for the stand made upon the rock, which was found at a depth of a few inches below the surface of the soil. Before the surface of the cement was finally set it was carefully levelled, the base put into position, and the mounting of the telescope proceeded with. The integrating apparatus was placed in a small marquee tent, a few yards to the north of the hut. Small slabs of concrete were also made in convenient situations, to carry the galvanometers, &c. As the photometer box attached to the equatorial added considerably to the length of the apparatus, it was necessary that the hut should be of somewhat larger dimensions than that generally adopted by the rest of the expedition; otherwise it was very much of the pattern of that which the Governor had caused to be constructed prior to our arrival at St. George, and which answered admirably in all respects. Round the hut and tents a deep trench was cut, with an outfall leading down the slope towards the sea to carry off the rain-water collected by the roofs. Our chief difficulties, indeed, were due to the frequent rains and constant humidity. At times the ground became worked into a sort of quagmire. By the 19th everything was in fair adjustment, and during the subsequent ten days the various members of the party were assiduously practised on all available occasions in their duties. The driving clock of the equatorial gave trouble in the outset, but it was eventually got into order, and on the day of the eclipse, and for some days previously, ran sufficiently well. The constant dampness of the ground, and consequent absence of dust, probably contributed to its good behaviour.

The duration of the total phase of the eclipse at Hog Island was about 230 seconds. We found that a simple and sufficiently accurate method of informing the party as to how this time was speeding, and of the amount of time still left at intervals of 15 seconds before the end of totality, could be obtained by observations made with a 14-second sand-glass, such as is employed on shipboard in heaving the log.

The arrangement of the party was as follows :—

| | |
|---|---|
| Integrating box . . . . | Lieutenant ANGUS DOUGLAS. |
| Galvanometer . . . . . | Mr. WEBB. |
| Bar photometer . . . . | Lieutenant BAIRNSFATHER. |
| Recorder . . . . . . . | Mr. ROBERT JACKSON. |

These instruments were placed close together in a small marquee. Each observer had in addition a man to charge and connect up a battery of Grove cells for the glow lamps.

| | |
|---|---|
| Equatorial photometer . . | Professor T. E. THORPE. |
| Galvanometer . . . . . | Mr. H. A. LAWRANCE. |
| Disc observations . . . . | Captain ARCHER. |

On the day before the eclipse the following instructions were issued to the observers in charge of the integrating apparatus :—

### *Instructions to Lieutenant* DOUGLAS. (*Integrating Box.*)

1. The eclipse begins at 6hr. 12m. L.M.T. Totality commences at 7hr. 10m., and lasts about 230 seconds.

2. It is desirable that on the morning of the eclipse you should be ashore not later than 6 A.M. (It is assumed that your integrating box, leads to galvanometer, glow lamp, and resistance apparatus are left in position over night.) Ascertain that the box is in proper azimuth, and test by the Abney level that the inclination is about 19°.

3. See that the connections to the glow lamp are properly made, and that the galvanometer is levelled on the cement foundation and is in adjustment.

4. Give instructions to have a battery of 7 cells in readiness for you, not later than 6.30: 6 cells to be connected up, the seventh to be reserved in case of accidents. See that you have actually 6 cells connected up before you begin.

5. At 6.30 connect up all leads, see that your lamp works properly, and that the intensity of the light responds to the screw of the resistance apparatus.

6. The back edge of the wooden piece carrying the lamp may be conveniently placed at Division 50 of the graduated scale. This, with the resistance apparatus open, will probably give you more light than you require. If at the moment of totality, and with the lamp full on, the coronal light is greater than that of the glow lamp, push up the lamp to Division 30. If you have occasion to move the lamp from 50 (which is very improbable), be very careful to note the particular distance from the screen at which you place it.

7. At 7·0 request Mr. WEBB and the man who records his readings to take up their stations at the cement slab. Take up your own position at the integrating box. Mr. WEBB's position to be such that he readily hears your command to read.

8. As the light decreases just before totality, that is between 7.0 and 7.10, turn the light up or down with the screw, so as to follow the decrease, so that after the moment that totality begins you may be able to begin your comparisons with the least possible delay.

9. Intimation that totality has begun will be given to the party by Quartermaster FOLLETT, who will call out 230. At intervals of 15 seconds he will call out the number of seconds still to elapse before totality ends.

10. When you have made your adjustment by the screw as carefully as you can, call out "read" to Mr. WEBB; do not turn the screw again until you hear him give his reading to the man who records. Again work the screw, make a second adjustment, and again call out "read," and again wait until Mr. WEBB has given his reading before you begin again. If this point is not attended to, the needle will be in such rapid oscillation that it will be impossible to get an accurate galvanometer reading.

11. Experience shows that 12 readings may be taken in 100 seconds, but it is not advisable that you should attempt to make more than 12 comparisons during "totality." Recollect that a few readings carefully and deliberately done are worth far more than a large number made hurriedly. Do not touch the position of your lamp at the end of your observations.*

12. Be careful not to fatigue your eye by looking too much at the Sun during the first stage of the eclipse. Insist that all talking ceases after 7.

*Instructions to Lieutenant* BAIRNSFATHER. (*Bar Photometer.*)

1. The eclipse begins at 6hr. 12m.; totality commences at about 7hr. 10m., and lasts about 230 seconds.

2. It is desirable that you should be ashore not later than 6 A.M. (It is assumed that your photometer bar, leads to galvanometer and to glow lamp, stand for galvano-

* This instruction was given in order that the position of the lamp might be verified after the observations were concluded.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meter, &c., are left in position on Saturday evening.) Ascertain that your photometer is in the proper azimuth ; test by the Abney level that its inclination is about 19°. Fasten the front rod securely down, so that on running the lantern backwards and forwards it works smoothly and without shaking the bar unduly.

3. See that the connections to the glow lamp are properly made ; next see that the galvanometer is levelled and in adjustment.

4. Give instructions that a battery of 7 cells should be in readiness for you not later than 6.30. Only 6 cells are to be connected up, the seventh to be in reserve in case of accident.

5. At 6.30 connect up all leads, see that your lamp works properly, and take a reading of your galvanometer. Go round to the back of your tent and see that you have actually 6 cells connected up.

6. At 7.0 request Mr. JACKSON to take up his station at the end of your table, and get ready to record. Go round to the galvanometer again and carefully note the reading of the needle, which Mr. JACKSON is to record. At 7.5 take up your position at the photometer bar.

7. As the light wanes follow up with the lantern, so as to get it into position with the least possible delay after the moment totality begins.

8. The preliminary drill has shown that 12 sets of double readings may be taken during the duration of totality. Do not, however, aim at doing more than 7 or 8 sets (in all 14 or 16 readings). A few readings carefully and deliberately done are worth far more than a large number taken very hurriedly.

9. When you have taken your last reading let the lantern remain as you placed it for the reading, in order that after the eclipse its position may be verified. Be careful to note on which side the middle point of the photometer bar the readings are taken.

10. There will probably be sufficient light during totality to see readily the numbers on the photometer bar; but, in case you have difficulty, it will be advisable to have a lighted lantern in readiness under your table.

11. At the end of totality, and therefore at the conclusion of your readings, again note the position of the galvanometer needle and record the deflection.

12. Be careful not to fatigue your eye by looking too much at the Sun during the first stage of the eclipse. All talking to cease at 7.0.

*Observations on the Day of the Eclipse.*

The general character of the weather, as noted during the ten days prior to the date of the eclipse, rendered it very doubtful whether any photometric observations would be at all possible at the time of totality.

The following Table will serve to indicate the condition of the sky at about the hour of the eclipse on successive days from August 17th to the 28th.

The amount of cloud is given on the scale from 0 to 10.

| | | Cloud. | |
|---|---|---|---|
| Aug. | 17 | 5 | Sun seen through haze. Clouded at times. |
| ,, | 18 | 3 | Sun unclouded at time of totality. |
| ,, | 19 | 3 | ,, ,, ,, |
| ,, | 20 | 2 | ,, ,, ,, |
| ,, | 21 | 4 | Sun seen through thin cloud. |
| ,, | 22 | 4–5 | Sun seen through haze. Much rain in night. |
| ,, | 23 | 5 | ,, ,, ,, ,, |
| ,, | 24 | 5–6 | Sun frequently clouded. |
| ,, | 25 | 8–9 | Sun clouded over; much rain at times. |
| ,, | 26 | 6–7 | Sun seen through faint clouds. |
| ,, | 27 | 8–9 | Dense clouds. No Sun; much rain at times. |
| ,, | 28 | 7–8 | Hazy at time of totality. Strong east wind with showers at times. |

The observing party left the "Fantôme" shortly before daybreak on the morning of the eclipse, and in a short time everything was in readiness for the observations. The sky was almost completely clouded over. A light breeze from the E.S.E. drove up sluggishly moving cumuli in great detached masses, some as high as 40° above the horizon, *i.e.*, double the height at which the Sun would be at time of totality. The high land of Grenada was completely enveloped in cloud, and heavy rain was falling in the middle and over the western slopes of the island. Over the low land of Point Fort Jeudy, across the bay, behind which the Sun would come up, was a mass of cumuli, with flattened bases, seemingly motionless. At 6.15 there was a slight shower of rain, and at 6.18 the partially eclipsed Sun was seen for a few seconds. In spite of the fact that the Solar disc was being rapidly obscured, the clouds were gradually breaking up into detached masses. By about 6.40 the greater portion of them had drifted away to the North. The equatorial was then put on the Sun, and the gradually diminishing crescent observed by reflection from the photometric screen. The clock went fairly well, and no adjustment was necessary to keep the limb in contact with the pencilled line of the image on the screen; indeed at no time during the totality was the edge separated from the circle by more than the thickness of the pencil line itself. The shadow of the Moon was plainly visible on the white disc. The moment of totality was 7hr. 10m. 14.6s. (L.M.T.), the calculated time as determined by interpolation from the data furnished by Mr. HIND for Caliveny and Point Salene, was 7hr. 10m. 18s. With respect to the observation, it may be stated that it was determined by means of a chronometer, the error and rate of which had been ascertained from observations of double altitudes made during the preceding 10 days by Captain ARCHER.

After a few moments' observation of the corona, the structure of which was admirably pictured on the white screen in the equatorial, the photometric comparisons were begun in the order previously fixed upon.

In all, 15 comparisons were made out of the 16 originally intended. At about 60 seconds from the calculated end of totality, a dark cloud swept over the corona, rendering all further observation impossible.

*Reduction of the Observations.*

The lamp used in the equatorial photometer had the values given in Table I. in Siemens units, reduced to a distance of 1 foot from the screen.

TABLE I.

| Measures of potential. | Intensity of light reduced to 1 foot from screen. |
|---|---|
| 24 | ·005 |
| 23 | ·007 |
| 22 | ·010 |
| 21 | ·0145 |
| 20 | ·020 |
| 19 | ·027 |
| 18 | ·036 |
| 17 | ·050 |
| 16 | ·066 |
| 15 | ·089 |

The lamp was 21·25 inches from the screen during the eclipse; hence the real values of the lamp were higher, but, as it is an inconvenient distance at which to compare the values obtained by the different instruments, an uniform distance of 12 inches from the screen has been adopted.

The same remark applies to the lamp used by Lieutenant DOUGLAS. The measures of potential in intensity of light are given in Table II.

TABLE II.

| Measures of potential. | Intensity of light reduced to 1 foot from screen. |
|---|---|
| 10·0 | ·0024 |
| 9·0 | ·0036 |
| 8·0 | ·0040 |
| 7·5 | ·0055 |
| 7·0 | ·0074 |
| 6·5 | ·0104 |
| 6·0 | ·0135 |
| 5·5 | ·0183 |
| 5·0 | ·0258 |
| 4·5 | ·0340 |



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During the eclipse this lamp was really 21·6 inches from the screen, and, as in the former case, the actual values of the light were higher.

The numbers in the above tables are graphically represented in the following curves, from which the results of the observations were measured.

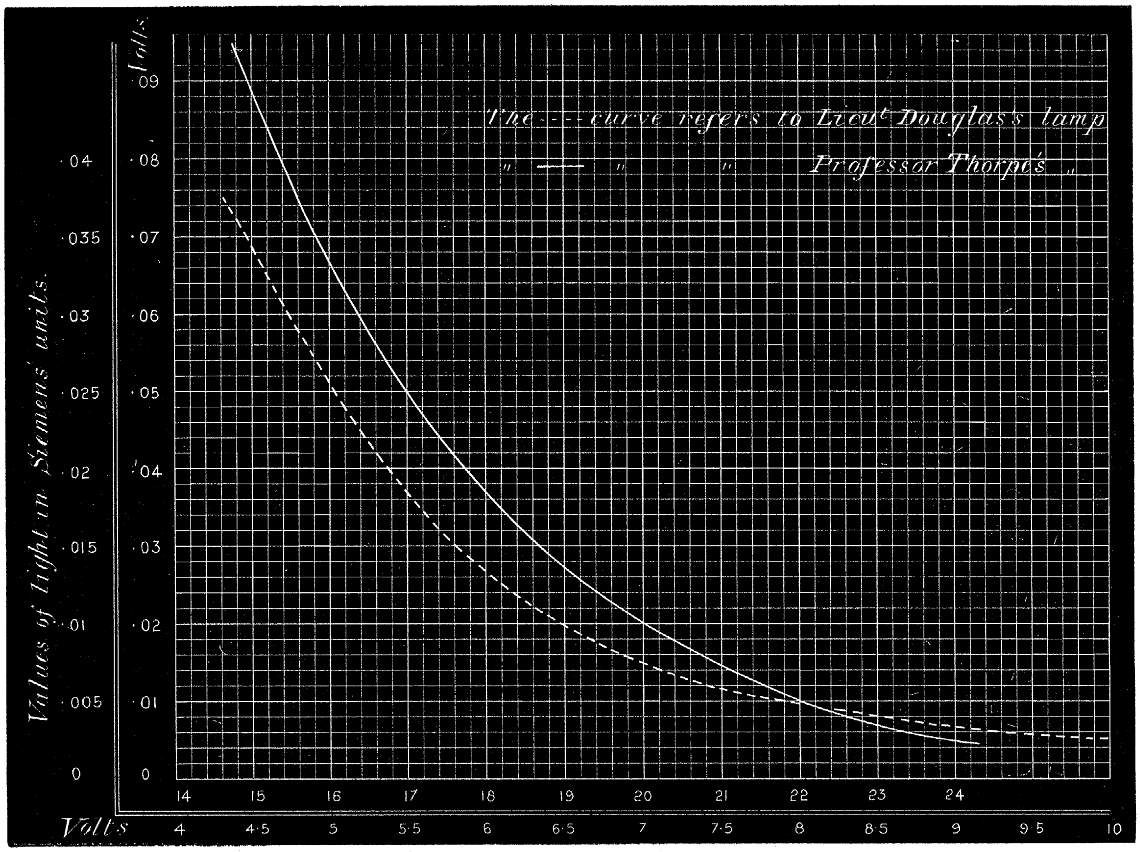


Table III. gives the value in light of the readings on the equatorial photometer. The numbers of the grease spots in Column I. correspond with the order in which they were read. Column II. gives the calculated distance of each spot from the Sun's centre in terms of the Solar diameter. Column III. gives the readings on the voltameter; and Column IV. the corresponding value of the light in Siemens units. Column V. gives the approximate time in seconds after the beginning of totality when the several readings were made.



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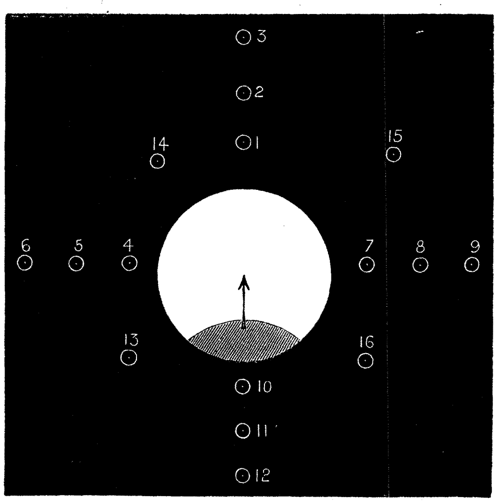
TABLE III.—Readings on the Equatorial Photometer reduced to the Values of Light Intensity.

| I. | II. | III. | IV. | V. |
|---|---|---|---|---|
| | | | | seconds. |
| 1 | 1·55 | 15·8 | ·070 | 10 |
| 2 | 2·66 | 18·3 | ·033 | 20 |
| 3 | 3·66 | 20·3 | ·019 | 30 |
| 4 | 1·61 | 16·5 | ·058 | 40 |
| 5 | 2·55 | 17·5 | ·043 | 50 |
| 6 | 3 44 | 19·4 | ·024 | 60 |
| 7 | 1·25 | 19·8 | ·021 | 70 |
| 8 | 2·16 | 21·4 | ·012 | 80 |
| 9 | 2·60 | 24·0 | ·005 | 90 |
| 10 | 1·11 | 18·0 | ·036 | 100 |
| 11 | 2·16 | 21·5 | ·013 | 110 |
| 12 | 3·16 | 23·5 | ·005 | 120 |
| 13 | 2·16 | 23·0 | ·007 | 130 |
| 14 | 2·33 | 23·5 | ·005 | 140 |
| 15 | 2·33 | 23·5 | ·005 | 150 |

Fig. 6 shows the position of the several spots as seen on the photometer screen. The arrow and shaded segments show the apparent direction of the Moon's path across the Solar disc.

Fig. 6.




The numbers correspond with the order in which the readings were made.

Table IV. gives the value of Lieutenant DOUGLAS's readings, and Table V. those of Lieutenant BAIRNSFATHER. It must be remembered that Lieutenant DOUGLAS's instrument measured the total light from the corona with only a small portion of the light from the sky, whereas the bar photometer as used by Lieutenant BAIRNSFATHER measured the light from the corona together with that from a large portion of the sky. Hence the readings on the bar photometer are necessarily higher than those obtained by the integrating box.

TABLE IV.—Readings on the Integrating Box reduced to Values of Light Intensity.

| Voltameter readings. | Value of light at 1 foot from screen in Siemens units. | Approximate time when readings were made from beginning of totality. |
|---|---|---|
| 5·4 | ·0197 | 15 |
| 6·2 | ·0122 | 30 |
| 5·9 | ·0142 | 45 |
| 7·0 | ·0075 | 60 |
| 6·8 | ·0085 | 75 |
| 7·1 | ·0070 | 90 |
| 7·3 | ·0065 | 105 |
| 7·3 | ·0065 | 120 |
| 7·7 | ·0054 | 135 |
| 7·8 | ·0051 | 150 |
| 8·3 | ·0045 | 165 |
| 8·8 | ·0040 | 180 |
| 8·9 | ·0035 | 195 |
| 9·3 | ·0030 | 210 |
| 9·4 | ·0027 | 215 |
| 9·4 | ·0027 | 220 |

TABLE V.—Readings on the Bar Photometer reduced to Values of Light Intensity.
Value of the lamp = 0·133 unit.

| Distance of lamp from screen in inches. | Equivalent value in Siemens unit at 1 foot. | Approximate time of reading. |
|---|---|---|
| 33·5 | ·0160 | 50 |
| 34·4 | ·0152 | 70 |
| 36·2 | ·0137 | 90 |
| 39·1 | ·0118 | 110 |
| 39·6 | ·0115 | 130 |
| 44·1 | ·0093 | 150 |
| 46·4 | ·0084 | 170 |
| 47·8 | ·0079 | 190 |
| 48·0 | ·0078 | 210 |
| 47·8 | ·0079 | 220 |
| 48·5 | ·0077 | 230 |

It will be noticed that Lieutenant BAIRNSFATHER'S first reading was made when 50 seconds of the totality had passed. The delay was due to the circumstance that it was found necessary to diminish the number of cells connected up after totality had begun, and hence a new reading of the galvanometer was needed before the observations could be commenced. The actual time of beginning could only be very approximately known, but from trials made subsequently it is probably accurate to within 5 or 6 seconds.

It will also be observed that both Lieutenant DOUGLAS and Lieutenant BAIRNSFATHER continued to read after the Moon and corona were actually obscured by cloud. Of course neither of the observers was able to notice the fact of the obscuration without looking up from his instrument. The passage of the cloud was, however, readily noticed on the screen of the equatorial photometer, and the time of obscuration during the phase of totality was noted. It occurred, as already stated, at about 1 minute from the calculated end of totality.

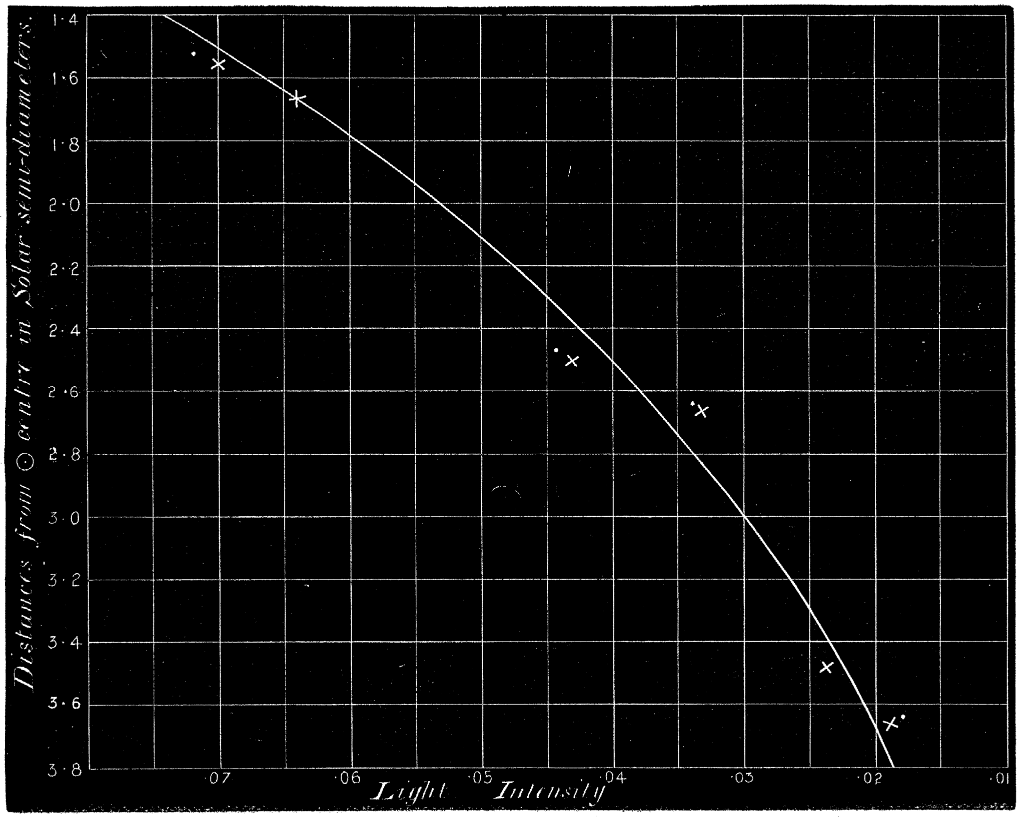
The observations of all these observers show in the clearest manner that the results are affected by haze after the first 60 or 70 seconds of totality. Thus, the first six readings on the equatorial photometer are fairly concordant, but after 1 minute had elapsed the light intensities begin to decrease rapidly. Thus, spots 7 and 10, which were considerably nearer to the limb than spots 1 and 4, show a considerably less intensity, and the differences are far greater than could be accounted for by any possible variation of local intensity in coronal light.* Lieutenant DOUGLAS's readings also show a sudden drop at about 60 seconds from the beginning of totality, and they continue to decrease steadily and in precisely the same manner as those of Lieutenant BAIRNSFATHER.

This result is indeed what might have been anticipated. It must be remembered that the air was practically saturated with moisture; a slight shower had fallen even a few minutes before totality, and the lowering of the temperature consequent on the obscuration of the Solar disc would inevitably cause the gradual precipitation of moisture from air already charged to saturation.

If we assume, therefore, that we are justified in regarding the first six observations made with the equatorial photometer as valid, we obtain the following curve as showing the photometric intensity of coronal light at varying distances from the Sun's limb expressed in terms of Solar semi-diameters from Sun centre.

* The photographs show that no such variations in local intensity were present.

Fig. 7.




Curve showing relation between photometric intensity of coronal light and distance of corona from Sun's limb.

It will be quite obvious, from the character of this curve, that the diminution in intensity does not vary according to the law of inverse squares. To show the degree of departure we have calculated the intensity, on the basis of the law, at several points and compared them with the values taken from the curve at the same points.

| Distances in Solar semi-diameters. | Photometric intensity. | |
|---|---|---|
| | Observed. | Law of inverse squares. |
| 1·6 | ·066 | ·066 |
| 2·0 | ·053 | ·042 |
| 2·4 | ·043 | ·029 |
| 2·8 | ·034 | ·022 |
| 3·2 | ·026 | ·016 |
| 3·6 | ·021 | ·013 |

In comparing the observations of Lieutenant DOUGLAS and Lieutenant BAIRNSFATHER with those made during the 1878 Eclipse it must be remembered that the conditions of observation on the two occasions were widely different. The observations in the West Indies were made at the sea-level, in a perfectly humid atmosphere, and with the Sun at no greater altitude than 19°. Professor J. W. LANGLEY observed from the summit of Pike's Peak, which is 14,100 feet above the sea, in a relatively dry atmosphere, and with the Sun at an altitude of 39°. Dr. J. C. SMITH's position at Virginia City, Montana, was about 6,000 feet above the sea-level, and the Sun's altitude at the time of observation was about 44°. If we have regard then to the extinction of the coronal light in the Earth's atmosphere, it follows, *cæteris paribus*, that the observations during the 1886 Eclipse should show a much lower photometric intensity than those of 1878, even if the intrinsic brightness of the corona was the same on the two occasions.

It will be a matter of remark that the brightness of the corona at the various points measured is very inferior to that of the Moon's surface. The value of the light from the full Moon has been variously estimated, but it is not an unfair estimate to take it as ·02 of a candle at 1 foot distance. Supposing the whole surface of the Moon to be of equal brightness, the brightness of the Moon's image on the photometric screen used in the equatorial telescope compared with moonlight itself would have been very closely 60 × ·02 candle, or 1·2 candles. No matter what part of the image fell on the grease spots, it would have required this illumination to have made the grease spots disappear. If we take the highest reading of the corona measured, we find that it is ·07 of a Siemens unit, or about ·06 candle. It thus appears that the brightness of the brightest measured part of the corona (1·55 Solar semi-diameters) was 200 times less bright than that of the surface of the Moon, whilst the furthest spot at 3·66 Solar semi-diameters, having a value of ·019 Siemens unit, or ·015 candle, was only $\frac{1}{800}$ of the brightness.

The highest value of the coronal light, measured in the ordinary photometer, was about ·02, or equivalent to that of the full Moon. It is evident therefore that, even when taking into account the greater angular area which the corona occupied, the brightness of the corona was very much greater close to the limb than elsewhere. The photographs which were taken show this fact. A dense image of the Moon might be secured on plates such as were used at the eclipse in the $\frac{1}{20}$th of a second. The photographs which were taken of the corona varied in exposure from half a second to 100 seconds. Even with the first named exposure the corona close to the limb was much over exposed, showing the intense brightness of that part, whilst the image of the highest part of the corona measured was hardly visible. Owing to the variable quantities of cloud during totality, it would be unfair to try to make any comparison between the brightness of the corona at the poles and at the equator, though, had no cloud intervened, the arrangements adopted would have enabled such to be done. Nor is it worth while to endeavour to establish any law for the decrease of brightness of the corona in terms of its distance from the limb. We have, however, in the measures given, obtained results which will be of use in comparing the brightness of the corona on this occasion with that of other future eclipses; and we believe that measurements of the brightness obtained by the plan adopted, or by photography, will become a necessary observation in determining what connection, if any, the Sun-spot periods have with the coronal phenomena.

We have to express our acknowledgments to Mr. H. A. LAWRANCE for the very ready and efficient aid which he rendered in mounting the equatorial, and in assisting in making the photometric measurements.

To Captain ARCHER and his officers, Lieutenants DOUGLAS and BAIRNSFATHER, we are also greatly indebted for the lively and eminently practical interest which they manifested in the work of the expedition generally, and especially for their zealous co-operation in the particular observations which had been entrusted to us. Indeed, the entire crew of the "Fantôme" laboured in the most willing and cheerful manner, often under circumstances of considerable personal discomfort, to promote the success of the expedition in every possible way.

## APPENDIX.

*Observations made by* NEWCOMB'S *Method on the Visibility of Extension of the Coronal Streamers at Hog Island, Grenada, by Commander* ARCHER, *R.N.*

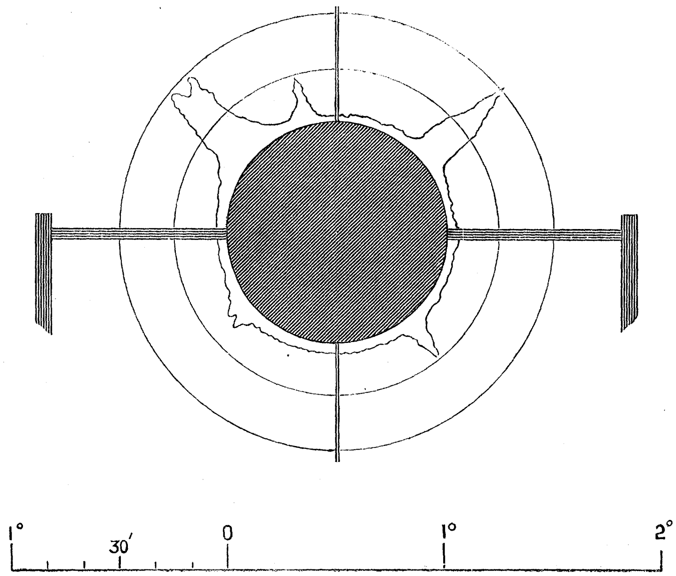
1. A 9-inch disc was erected on a pole fastened to the N.W. corner of the observatory, much in the manner suggested in the instructions; the distance of the eye-piece from a plumb-line hanging under the centre of the disc frame was exactly 40 feet.

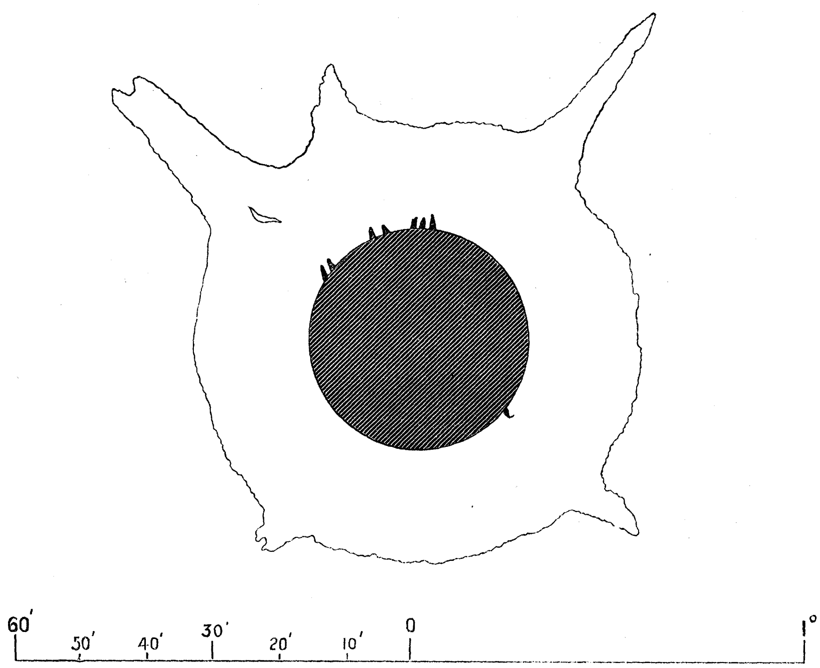
2. As a means of measuring the length of the streamers of the corona, I had fitted two copper circles concentric with the disc, supported on a light iron cross; the diameter of the inner circle was $1\frac{1}{2}$ disc diameter ($13\frac{1}{2}$ inches), that of the outer one 2 disc diameters (18 inches).

3. In order to localise the position of the streamers, I decided to look upon the disc as a compass card, with the North point vertically upwards; the arms of the iron cross therefore indicated the cardinal points.

4. The iron crossbar which carried the eye-piece I had lengthened to 18 inches, in order to increase the limits of adjustment, and also to admit of the Sun being observed when at the proper altitude (18° 48′) on several preceding days; owing to this circumstance, I feel considerable confidence in the Sun's having been nearly concentric with the disc at the beginning of totality, as on two previous days I timed the exact moment when the Sun's centre was behind the centre of the disc, and found the calculated altitudes at the time were between 18° 48′ and 18° 49′, the calculated altitude at commencement of totality being 18° 47′ 51″. The position of the eye-piece was adjusted on the previous day, and required no further alteration.

5. I found the concentric wire circles of great advantage, as the streamers, when judged by eye alone, appeared to be much longer than they really were; and, had it not been for this device, I feel sure I should have over-estimated the distance to which they extended.




6. Half an hour before the commencement of totality I sat down in the shade, and a quarter of an hour before I had my eyes bandaged with a double thickness of black cloth; on the signal being given, I removed the bandage and observed through the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eye-hole a narrow fringe of very bright white light all round the wooden disc, with marked extensions to the N.E. and N.W., which both just reached the outer wire, though the outer portion was very faint. The N.W. one was rather forked, the N.E. one pointed. To N.N.W. was a fainter thin extension, which reached to the first wire; to S.E. was a similar one, also reaching to the first wire; and to S.W. was a very small double one hardly reaching half way to the first wire.

7. I then looked through a ship's telescope I had on a stand near me, and I observed red prominences under the N.W., N.N.W., and S.E. extensions, and also some prominences at North. To N.W. was a long tongue of flame about the colour of a candle flame, which appeared to be disconnected from the Sun's limb, and to extend to about 10′ from the limb; this estimation was made by aid of the afore-mentioned wires.

8. On a cloud passing over towards the end of totality I looked at the stars overhead, but there were so many in sight that I could not pick out what they were; I should say that, judging by the contrasts between their brightness, some of them must have been of the third or fourth magnitude.

9. At the eye-hole a linear inch on the disc subtended an angle of 68 minutes; thus, supposing the Sun were concentric with the disc at the beginning of totality, the streamers to the N.W. and N.E. would be about 45′ from the Sun's limb, those to N.N.W. and S.E. about 30′, that to S.W. about 22′, and the general ring of light of the corona probably about 18′.

10. I observed a light film of cloud to be passing over the corona for several seconds before it was hidden by the cloud.

11. Explanation of the diagrams (p. 383):—

The upper figure represents the wooden disc with its supports and wires, and the irregular ring of the corona and streamers showing round it, as seen at the commencement of totality. The second figure is a reproduction of the first on a larger scale, with the disc removed; the dark circle represents the Moon, and the black dots show the prominences that were noticed. A scale of degrees and minutes is attached to each figure. The vertex is towards the top of the paper.

ROBERT H. ARCHER, *Commander.*

*H.M.S. "Fantôme," Grenada.*