XII. *On the Determination of the Photometric Intensity of the Coronal Light during the Solar Eclipse of April* 16*th*, 1893.

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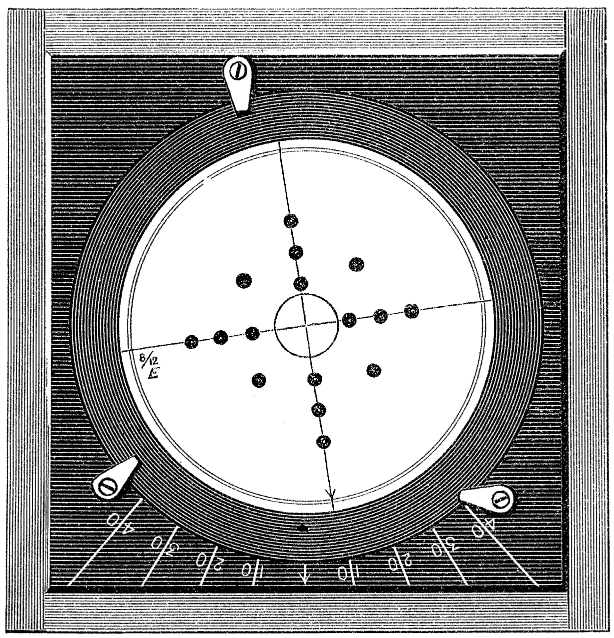
IN the Introduction to our paper "On the Determination of the Photometric Intensity of the Coronal Light during the Solar Eclipse of August 28th, 1886," which the Society did us the honour to print in the 'Philosophical Transactions' (A, 1889, p. 363), we gave an account of the attempts which had been made from time to time since the eclipse of December 22, 1870, the first occasion on which such measurements were made, to ascertain the amount of light emitted by the corona. So far as we know no other attempt of the kind has been made since the date of our last paper. We may therefore at once pass to the description of the methods adopted on the present occasion.

The methods, as well as the instruments, used by us for the measurement of the coronal light during the eclipse of April 16th, 1893, were substantially the same as those employed in Grenada during the eclipse of August 28th, 1886, with certain modifications suggested by our experience on that occasion. For an account of the principle of these methods, as well as for the description of the instruments themselves, we may refer to the paper above cited. It will suffice here to say that one instrument was designed to measure the comparative brightness of the corona at different distances from the moon's limb, whilst a second was arranged to measure the total brightness of the corona, excluding as far as possible the sky effect. The first instrument, from the mode in which it was constructed, will be called the equatorial photometer; the second will be termed the integrating photometer. In both cases the principle of photometry adopted was that of BUNSEN, the intensity of the coronal light being compared with that of a glow-lamp, according to the method of ABNEY and FESTING ('Phil. Trans.,' 1886, 'Proc. Roy. Soc.,' 1887, 43). In the case of the equatorial photometer, a telescope by SIMMS, lent by the Astronomer-Royal, was employed. It had an aperture of 6 inches and the object-glass had a focal length of 78 inches, forming an image of the moon 0·76 inch in diameter. The image was received on a circular white screen contained in the photometer-box and placed 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 clockwork, the image could be kept stationary within the circle. The screen was of RIVES' paper of medium thickness, and round the pencilled circle a series of small grease-spots about $\frac{1}{8}$ of an inch in diameter were made. For the mode of making the grease-spots and testing the screens we may refer to our original paper. Fig. 1, reproduced from this paper, shows the screen mounted in its circular frame. The screen could be rotated so as to bring the spots into any desired angular position, and it could be removed at pleasure by releasing it from the buttons which held it within the frame. The box to hold the screen in the focus of the telescope and the VARLEY carbon resistance-apparatus used to increase or diminish the light of the standard glow-lamp were identical with those employed during the 1886 eclipse, and are described in our previous paper (*loc. cit.*, pp. 367, *et seq.*).

Fig. 1.



The most important variations in the mode of making the observations, as compared with the previous measurements, consisted in the manner of connecting up the lamp, resistance-apparatus, and galvanometer, and in the method of reading the current-strength. On the former occasion the brightness of the lamp was increased by adding resistance to the shunt; consequently in the measures made the highest readings of the galvanometer corresponded with the lowest intensity of light. On the present occasion the better plan of putting the galvanometer and resistance in the main circuit was employed; hence high readings of the galvanometer mean high intensities of light. The lamps used during the present eclipse were EDISON-SWAN'S 8 volts, 5-candle power. The relation between the current-strength and light intensity

expressed in terms of SIEMEN'S amyl-acetate lamp, in the case of the two lamps actually employed, is seen from the following tables.

LAMP C 6. Used with the Equatorial Photometer. Mark 184 D.

Amperes.	Light units.	Amperes.	Light units.	Amperes.	Light units.
0·8	·004	1·00	·030	1·15	·102
0·85	·0065	1·01	·034	1·20	·140
0·9	·0100	1·05	·048	1·25	·193
0·95	·017	1·10	·073	1·30	·262

LAMP C 3. Used with the Integrating Photometer. Mark 185 D.

Amperes.	Light units.	Amperes.	Light units.	Amperes.	Light units.
0·8	·002	1·00	·026	1·20	·093
0·85	·005	1·05	·035	1·25	·125
0·90	·010	1·10	·048	1·30	·167
0·95	·017	1·15	·066		

The readings of current strength in the case of the equatorial photometer were made by means of a Weston ammeter, which is especially convenient for the purpose. In the case of the integrating instrument an Evershed ammeter was used. These were procured for us by Professor AYRTON, and were carefully tested by him in order to ensure that their indications were strictly comparable. He was also good enough to select the glow-lamps for us and to have them standardised in his laboratory. On again standardising them after making use of them for the observations they were found to be practically unchanged. Our best thanks are due to Professor AYRTON for the interest he displayed in our work, and for the great amount of time and trouble he spent on our behalf.

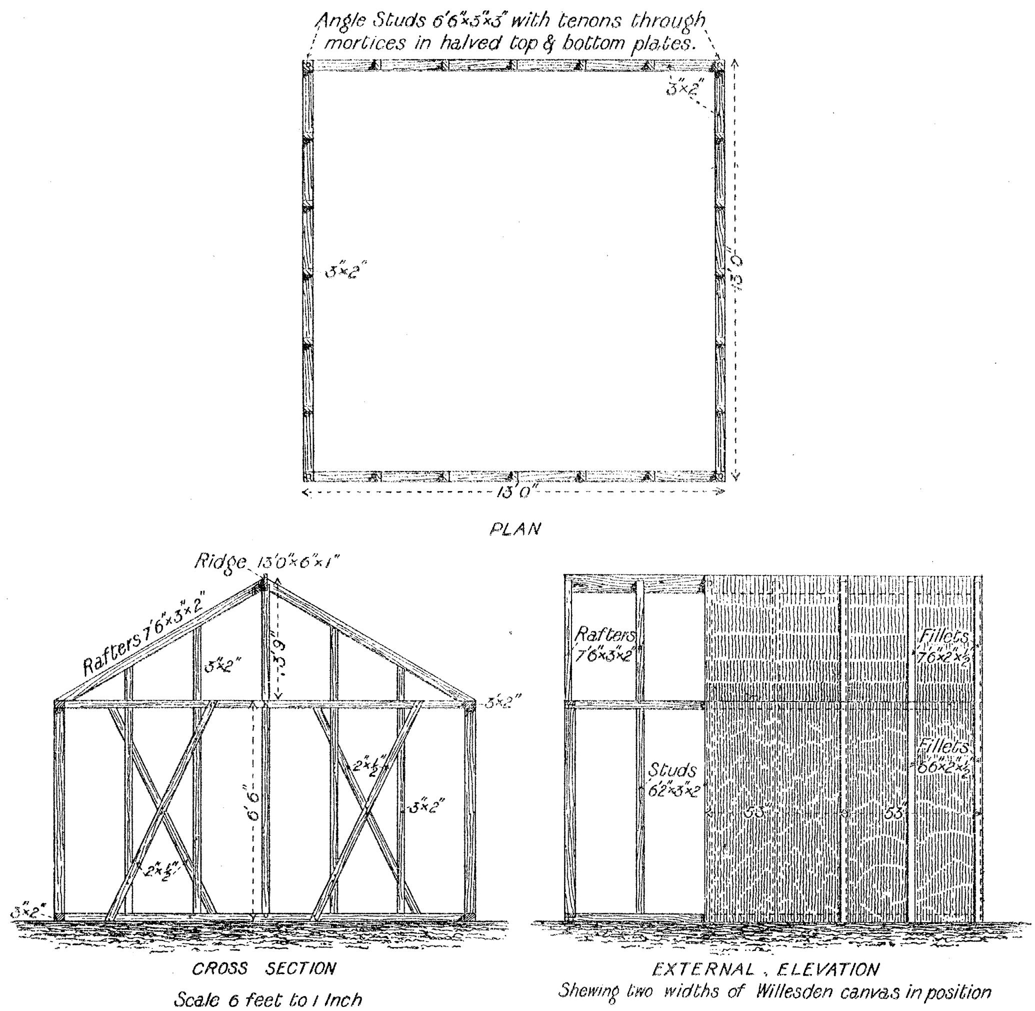
As regards the rest of the work, nature of battery, instructions to observers, &c., the details were identical with those already given in our previous paper.

The Joint Committee representing the Royal Society, the Royal Astronomical Society, and the Solar Physics Committee of the Department of Science and Art, which was charged with the superintendence of the arrangements for observing the Eclipse of April 16, 1893, directed that the photometric measurements of the coronal light should be part of the work of the expedition to be despatched to Senegambia.

Professor THORPE (who was in charge of the expedition) was entrusted with the equatorial photometer measurements, and was assisted by Mr. P. L. GRAY, B.Sc., who undertook the galvanometer readings, whilst the observations with the integrating photometer were to be made by Mr. JAMES FORBES, jun., of the Royal College of Science.

The station actually selected for the African party was Fundium, in Senegal, a small town on the south bank of the Salum river, about thirty miles from the sea and near the central line of the shadow. The observers were sent out from England by mail-steamer to Bathurst, the head-quarters of the British possessions on the Gambia, and thence transferred to H.M.S. *Alecto,* which vessel, by the kindness

Fig. 2.



HUT used by British Eclipse Expedition, 1893.

of the Admiralty, had been told off to assist the expedition. The *Alecto* left Bathurst for the Salum on April 2, and arrived at Fundium on the afternoon of the following day. M. ALLYS, the Administrator of the district, which is in French territory, received the party very courteously, and placed the ground in the rear of his house at their disposal. The best thanks of the expedition are due to the Administrator and to the French authorities for their kindness.

The position offered by M. ALLYS was well adapted to our work. It was enclosed

within a stockade, was conveniently near the moorings of the *Alecto,* and sufficiently removed from the huts of the people, who are here mainly Sereres and Wolofs, to secure the necessary privacy. The greater number of the packing-cases containing the instruments were landed before nightfall of the day of arrival, the ground being meanwhile measured out, and the positions for the various observing huts of the party assigned. With the help of the men of the *Alecto,* together with a few Sereres who were engaged to dig and to make concrete for the foundations for the equatorials, the erection of the huts and instruments proceeded as rapidly as the excessive heat would permit, and before the end of the week everything was in adjustment, and we had a clear six days before us for the necessary drill and final preparations. The huts used on this occasion were designed, and their construction in England superintended, by Quarter-Master Sergeant KEARNEY, R.E. As they answered their purpose remarkably well, being readily and quickly put together and taken down, and being sufficiently rigid when erected, it may be desirable to give a short account of them here in view of future expeditions. The design is seen in plan, cross-section, and external elevation in fig. 2, which is drawn to a scale of 6 feet to an inch.

The materials required are :—

		feet.
8 pieces white deal scantling	$3'' \times 2'' \times 13'$	= 104
2 ,, ,, ,, ,,	$3'' \times 2'' \times 10'$	= 20
12 ,, ,, ,, ,,	$3'' \times 2'' \times 7' 6''$	= 90
18 ,, ,, ,, ,,	$3'' \times 2'' \times 6' 2''$	= 111
		325
Allowance for waste in trimming . .		25
		350
4 pieces white deal scantling	$3'' \times 3'' \times 6' 6''$	= 26
Allowance for trimming		2
		28
1 ridge piece	$6'' \times 1'' \times 13'$	= 13
Allowance		1
		14
12 pieces for battens	$3'' \times \frac{1}{2}'' \times 8' 6''$	= 102
Allowance for trimming		18
		120

Willesden canvas 53″ wide, 46 yards.

The canvas should be previously cut to the sizes required, viz.:—

3 pieces 28″ long.
6 ,, 6′ 6″ long.
2 ,, 6′ 6″ cut diagonally.

The canvas is fastened to the hut by means of fillets (as shown in the drawing). These should be $2'' \times \frac{1}{2}''$, cut into the following lengths: 18 pieces 7′ 6″ and 32 pieces 6′ 6″, making in all 343 feet. The studs and rafters should be fastened by 3-inch French wire nails (say, 3 lbs.), and the fillets over the Willesden canvas by 1-inch French nails (say, 1 lb.); these are easier to drive by unskilled hands than the ordinary kind, and are less liable to split the wood.

The climatic conditions at Fundium were wholly different from those with which we had to contend at Grenada. At the latter place our chief difficulties were due to the frequent rains and constant humidity.

At Fundium, on the other hand, we had excessive dryness; at noon there was often a difference of 20° F. between the wet and dry-bulb thermometers, and with the exception of the evening before the eclipse, there was not even a trace of dew at night. This excessive dryness, combined with the high temperature—it occasionally rose to 110° or 112° in the huts—was very trying to the woodwork. But our main trouble was the dust, which was excessively fine and light, and deposited itself as an impalpable powder over the apparatus, and greatly interfered with the proper running of the clocks. However, by covering the base of the huts with layers of the shells of some variety of *Cardium*, which were found in large numbers near the beach, and by frequently watering the ground, we to some extent kept down the cloud which every foot-fall otherwise raised.

On the afternoon of the 14th the weather changed slightly for the worse. Up to that time the wind had been mainly in the east, and the sky almost unclouded. On that day the wind went round to the west, the temperature fell considerably and there was more cloud and haze in the sky and a certain amount of dew in the evening.

On the 16th, the day of the eclipse, the conditions were slightly better as regards the amount of cloud, but the haze and general opalescence of the air was not less distinct. The morning was bright and clear, but the effects of the westerly winds were to be seen in the milky colour of the sky, and, as the sun rose higher, in the grey appearance of the heavens. During the whole period of the eclipse, however, the sky was cloudless, except for a few thin wispy cirri near the horizon, and although, of course, the temperature fell considerably as the phase of totality approached, there was not the slightest appearance of condensing moisture and there was no increase of cloud although a considerable increase of wind. In this respect the conditions were entirely different from those in the West Indies. At Grenada all the observations show, in the clearest manner, that the results were affected by

the precipitation of moisture after the first 60 or 70 seconds of the totality; dark clouds rapidly gathered in the neighbourhood of the disc, and at about one minute before the calculated end of the total phase the moon and corona were wholly obscured. The air was saturated with moisture; a slight shower had indeed fallen a few minutes before the beginning of totality, and the lowering of the temperature, consequent on the obscuration of the solar disc, undoubtedly caused the gradual condensation of moisture. Hence, therefore, we could only regard, at most, the first six out of the possible sixteen observations made with the equatorial photometer as valid; and only three, at the outside, out of the sixteen readings made by the integrating photometer were of any value as measuring the total brightness.

On the present occasion, owing to the much more favourable conditions, the greater number of the measurements made by the equatorial photometer, twenty in all, as well as ten measurements made by Mr. FORBES with the integrating photometer, are available. The results of these measurements are given in the following tables:—Table I. gives the value in light of the readings of the equatorial photometer. The numbers of 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 semi-diameter. Column III. gives the readings on the ammeter; and Column IV. the corresponding value of the light in SIEMENS' units at one foot. Column V. gives the approximate time in seconds after the beginning of totality when the readings were made.

TABLE I.—Readings on the Equatorial Photometer reduced to the value of Light-Intensity.

I.	II.	III.	IV.	V.
1	1·66	1·060	·058	10
2	2·70	1·015	·037	16
3	3·80	·954	·018	23
4	1·30	1·070	·061	30·5
5	2·88	1·021	·038	42
6	3·12	·951	·019	48·5
7	1·76	1·186	·137	61
8	2·32	·969	·023	71
9	3·28	·928	·015	79
10	1·70	1·088	·069	92
11	2·82	1·020	·039	101·5
12	3·88	·961	·021	107
13	2·46	·950	·018	121
14	2·46	·920	·013	131
15	2·42	·877	·009	141·5
16	2·64	·950	·018	151
1	1·66	1·110	·084	162
4	1·30	1·060	·058	172
7	1·76	1·170	·123	185
10	1·70	1·030	·042	193·5

Spots 1 and 10 are in the line of the apparent direction of the moon's path across the solar disc; it will be noticed that on repeating the readings one area has gained as much in intensity as the other has lost, whereas spots 4 and 7 which are at right-angles to the moon's apparent motion, have remained practically unchanged in intensity.

Table II. gives the value of Mr. FORBES's readings with the integrating photometer.

TABLE II.—Readings with the Integrating Photometer reduced to values of Light-Intensity.

No. of readings.	Ammeter reading.	Value of light at 1 foot from screen in SIEMENS' units.	Approximate time of readings from beginning of totality.
			seconds.
1	1·05	0·029	3
2	1·03	0·026	12
3	1·02	0·024	30
4	0·99	0·022	45
5	1·00	0·022	70
6	1·04	0·027	94
7	1·035	0·026	120
8	1·04	0·027	147
9	1·05	0·029	184
10	1·05	0·029	206
Average light = 0·026.			

The measurements with the equatorial photometer clearly show that the visual brightness of the corona of the 1893 eclipse varied within comparatively wide limits, and that, at all events close to the moon's limb, there were marked differences in local intensity. The readings of spots 1, 2, 3, and 10, 11, 12, which are at the opposite sides of the lunar disc are fairly concordant among themselves. Spot 7, which was comparatively close to the limb, was probably affected by the proximity of a prominence; it will be noticed that the readings were repeated at an interval of more than a couple of minutes and are in substantial agreement.

It may here be stated that anything in the nature of personal bias on the part of either observer was impossible from the very manner in which the work had to be done; Mr. GRAY, of course, could not see the comparisons actually made, nor could Dr. THORPE have any knowledge of the readings of the current strength at the particular moment of comparison; each portion of the joint work was therefore wholly independent. If the several values taken in the direction of the poles and equator are grouped as before, excluding Spot 7, for the reason above given, the averages, when treated as in our former paper, will be found to afford a curve almost

identical in character with that already given (*loc. cit.*, p. 380), showing, as formerly stated, that the diminution in intensity from the moon's limb outwards is less rapid than that demanded by the law of inverse squares.

The results are as follows :—

Distances in solar semi-diameters.	Photometric intensity.		
	Observed.		Law of inverse squares.
	1893.	1886.	
1·6	0·060	0·066	0·066
2·0	0·048	0·053	0·042
2·4	0·038	0·043	0·029
2·8	0·030	0·034	0·022
3·2	0·024	0·026	0·016
3·4	0·018	0·021	0·013

These numbers would appear to show that the actual brightness of the corona was probably not very dissimilar at the two eclipses, the slight apparent diminution observed during the 1893 eclipse being, in all probability, due to the haze or opalescence in the air which, as already stated, prevailed at the time. This haze, caused more by suspended and finely-divided solid matter than by precipitated moisture, undoubtedly contributed to the general sky-illumination at the time of totality. The actual gloom during this phase of the eclipse at Fundium was certainly much less than at Grenada in 1886. It must not, however, be forgotten that the altitude of the sun was very different on the two occasions. At Grenada it was only about 19°; the amount of cloud was from 7 to 8 (overcast = 10) at the time of totality; and much of it was in the neighbourhood of the sun; whereas at Fundium the sun's altitude was 52° and the sky was of a bluish-grey colour and practically free from cloud.

The effect of these different conditions in the sky in the neighbourhood of the disc is seen in Mr. FORBES's measurements when compared with those of Lieutenant DOUGLAS at Grenada. The ten fairly concordant observations at Fundium give an average value of 0·026 Siemens unit at one foot from the screen; the highest and probably the most accurate value observed by Lieutenant DOUGLAS fifteen seconds after totality, with the same photometer, although with a different lamp and galvanometer, was 0·0197.

The observations are not sufficiently precise to enable any valid comparison to be made between the brightness of the corona at the poles and at the equator, nor are they numerous enough to make it worth while to attempt to seek for the law

connecting the decrease of brightness of the corona in terms of its distance from the limb.

In conclusion we desire to acknowledge our great indebtedness to Captain LANG and the officers of H.M.S. *Alecto* for their ready assistance and for the zeal and intelligence with which they co-operated in the work of the expedition. The party is also under many obligations to Captain FESTING and the other officers of H.M.S. *Blonde* for their kindness and hospitality on the voyage home from Bathurst to Las Palmas.

[Since this paper was written we have to deplore the death, from fever, at St. Kitts, of Mr. Forbes. He was a young man of great promise, and a most careful and painstaking observer, and his amiable disposition and uniform courtesy endeared him to every member of the expedition.]