XV. *The Total Eclipse of the Sun, April 16th, 1893 —Report and Discussion of the Observations relating to Solar Physics.*

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25.11.96.

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PART I.—THE OBSERVATIONS.

I. INTRODUCTION.

THE results obtained by Professor RESPIGHI and myself during the eclipse of 1871 in India, in which part of the attack consisted in the employment of slitless spectroscopes—a method of work at which we had arrived independently—indicated the extreme value of such observations.

For my own observations in 1871 I had arranged a train of five prisms without either collimator or observing telescope. "I saw four rings with projections defining the prominences. In brightness, C came first, then F, then G, and last of all 1474K. Further, the rings were nearly all the same thickness, certainly not more than 2′ high, and they were all enveloped in a band of continuous spectrum."*

* "Nature," vol. 5, p. 218, 1872.

RESPIGHI's observations were made with a telescope of $4\frac{1}{2}$ inches aperture with a large prism of small angle in front of the object glass. A negative eyepiece magnifying 40 times and having a field view large enough to include the whole of the spectrum was employed. The principal results obtained by RESPIGHI were as follows* :—

"At the very instant of totality, the field of the telescope exhibited a most astonishing spectacle. The chromosphere at the edge which was the last to be eclipsed . . . . . . was reproduced in the four spectral lines C, D_3, F, and G, with extraordinary intensity of light . . . . . .

"Meanwhile the coloured zones of the corona became continually more strongly marked, one in the red corresponding with the line C, another in the green, probably coinciding with the line 1474 of KIRCHHOFF's scale, and a third in the blue perhaps coinciding with F."

"The green zone surrounding the disc of the moon was the brightest, the most uniform and the best defined."

My observation† was made intermediately between the two observations of Professor RESPIGHI. The observations may be thus compared :—

RESPIGHI	C	D_3	F.G.	Chromosphere and prominences at beginning of totality.
LOCKYER	C	1474 (faint)	F.G.	Corona 80 secs. after beginning of totality.
RESPIGHI	C	1474 (strong)	F.	Later.

I had no object glass to collect light, but I had more prisms to disperse it, so that with me the rings were not so high as those observed by RESPIGHI, because I had not so much light to work with; but such as they were, I saw them better, because the continuous spectrum was more dispersed, and the rings (the images of the corona) therefore did not overlap. Hence, doubtless RESPIGHI missed the violet ring which I saw; but both that and 1474 were very dim, while C shone out with marvellous brilliancy, and D_3 was absent.

In arranging for the eclipse of 1875 in Siam and the Nicobars, the method was further developed by the introduction of photography, and the first results of this extension were given in the report of the Eclipse Expedition of that year. They showed clearly that with the rapid dry plates of to-day a considerable increase of dispersion might be attempted.

The object glass employed on this occasion had an aperture of $3\frac{3}{4}$ inches and a focal length of 5 feet, while the prism had a refracting angle of 8 degrees.

Two photographs were obtained with exposures of one and two minutes respectively. Both are reproduced in the Report,‡ and they show only such

* 'Nature,' vol. 5, p. 237, 1872.

† 'Brit. Assoc. Report,' 1872, p. 331.

‡ 'Phil. Trans.,' 1878, vol. 169, Part 1, p. 139.

differences as can be attributed to difference of phase. The dispersion was very small compared with the size of the sun's image, so that the photographs present the appearance of an ordinary photograph of the eclipsed sun which is slightly distended in the direction of dispersion. The various prominences each show three images, two of which were identified with H_β, H_γ, while the others were found to correspond to a wave length of about 3957.

It was suggested (Report, p. 149) that this represented the H and K radiations of calcium, and this is fully confirmed by the results obtained in 1893, to say nothing of results obtained in other eclipses.

In addition to the protuberances, the photographs show a well defined circular boundary of the moon's limb at a position corresponding to H_γ. This was considered to be an indication that hydrogen was one of the substances existing in an incandescent state in the corona itself, for although coronal rings corresponding to H_β and H_δ were not photographed, their absence may possibly be accounted for by the fact that the plates employed were most sensitive to the H_γ region.

There are also indications of a continuous spectrum from the lower parts of the corona, shown by well defined structure running parallel to the direction of dispersion.

I next proceed to remark very briefly upon the photographic results obtained since 1875.

In 1878, near the sun-spot minimum, the method was employed by several observers, myself among them, but no *bright* rings were recorded. The maximum sun-spot conditions previously observed had entirely changed; indeed with a slit spectroscope the 1474 line was very feeble, and was only seen by a few of the observers, and hydrogen lines were similarly feeble.*

Part of my own equipment for this eclipse consisted of a small grating placed in front of an ordinary portrait camera, and with this I obtained a photograph showing only a very distinct continuous spectrum.†

The method was employed by Dr. SCHUSTER in Egypt in 1882; the camera was of 3 inches aperture and 20 inches focal length, with a prism having a refracting angle of 60°.‡

The single photograph obtained (which was not reproduced) was stated to show two rings, which were considered to be due to the lower parts of the corona, and therefore to correspond to true coronal light. The wave-length of one of these rings was measured to be 5315; it is due to the green corona line (1474K). The second was stated to be coincident with D_3. The ring in the green was particularly strong in the south-western quadrant, and hardly visible at some other points of the sun's

* 'American Journal of Science,' vol. 16, p. 243.

† With a duplicate grating I observed the spectrum of the eclipsed sun, and again in three different orders, saw nothing but continuous spectrum ('Nature,' vol. 18, 1878, p. 459).

‡ 'Phil. Trans.,' vol. 175, 1884, p. 262.

limb. The yellow ring was much fainter on the whole, but more uniform all round the sun.

In 1883 the same instrument used in Egypt in 1882 was employed, as well as a 6-inch achromatic telescope, and a concave ROWLAND grating of 5 feet focus, arranged for taking ring spectra in the first and second orders.

It is stated in the report* that the photographs "possess no features of interest," and neither reproductions, nor drawing, nor measurements are given.

The prismatic camera employed in the eclipses of 1882 and 1883 was again used in the West Indies in 1886. Only the spectra of some prominences seem to have been recorded. There is no mention of rings. The hydrogen lines as well as K and *f* are noted.†

While on the one hand the photographic results, to which reference has been made, certainly did not come up to the expectations raised by my observations of 1871, on the other, subsequent solar investigations confirmed my opinion that this was the best way of studying the lower parts of the sun's atmosphere, provided an instrument of much greater light-grasping power could be employed.

I determined, therefore, when arranging for the observations to be made during the eclipse of 1893, to renew the attack with the largest telescope and the greatest dispersion at my command.

The Solar Physics Committee is now in possession of a prismatic camera of 6 inches aperture. I decided, therefore, to employ it, all the more because the work on stellar spectra at Kensington had given abundant proof of its excellence.

The object glass of this instrument, corrected for the photographic rays, was constructed by the Brothers HENRY. The correction is such that it is unnecessary to incline the back of the camera, and hence some of the objections which have been made to the use of this form of spectroscope are overcome. The large refracting angle of the prism (45°) obviously increases the value of the instrument for eclipse work. This instrument was placed at the disposal of the Eclipse Committee, by the Solar Physics Committee, and was entrusted to Mr. FOWLER, who took the photographs at the African station.

Although no other instrument of this power was available, it seemed important that a series of similar photographs should be attempted at another point on the line of totality. A spectroscope belonging to the Astrophysical Laboratory of the Royal College of Science was lent for the purpose by the Department of Science and Art, and a siderostat used in conjunction with it was lent by the Royal Society. These instruments formed part of the equipment of the Brazilian expedition, and were placed in charge of Mr. SHACKLETON, Computer to the Solar Physics Committee.

The following sections give, first, reports of the operations at the two stations contributed by Messrs. FOWLER and SHACKLETON, in charge of the instruments at

* 'Phil. Trans.,' 1889 A, vol. 180, p. 122.

† 'Phil. Trans.,' 1889 A, vol. 180, p. 319.

the African and Brazilian stations respectively; then a detailed description of the phenomena recorded, followed by a discussion of the method employed in dealing with the photographs.

The spectrum of the corona and its possible variation, the wave-lengths and intensities of the prominence and chromospheric lines are next studied, and finally the loci of absorption in the sun's atmosphere are considered.

Much labour aud time have already been spent in dealing with the chemical part of the inquiry, and I have been driven to the conclusion that before the bearing of the eclipse observations on our knowledge of the spectrum of each chemical substance is given, much more inquiry must be undertaken (*a*) into the old observations, (*b*) into the spectrum of stars and nebulæ, and (*c*) into certain questions for which new observations are necessary.

This chemical part of the inquiry will, therefore, be set out in a future Memoir.

II.—The African Station (Mr. Fowler's Report).

Locality.

The station selected in West Africa as offering the greatest facilities, combined with good chances of fine weather, was Fundium (or Foundiougne, as it is called by the French), on the Salum River. According to the Admiralty Chart, the village is in latitude 14° 3′ N. and longitude 16° 30′ W. It was, therefore, only about six miles south of the central line of eclipse.

The expedition left Liverpool on the morning of March 18, 1893, by the British and African Company's s.s. *Teneriffe*, and arrived at Bathurst, on the Gambia, on March 31. Instruments and observers were there transferred to H.M.S. *Alecto*, the special service gunboat on the West Coast of Africa, then in charge of Lieutenant-Commander Lang, R.N. Leaving Bathurst on April 2, the party proceeded to the selected station, arriving there on April 3.

A very suitable site for the instruments was offered by the Administrator, in the grounds surrounding his own house, and it was at once accepted as satisfying all requirements. It was quite close to one of the wharves, and had the advantage of being partially enclosed. Vegetation in the neighbourhood was very sparse, and an almost perfectly clear horizon was obtained.

A neighbouring site was already occupied by M. Deslandres, of the Paris Observatory, when the British expedition arrived at Fundium.

With the assistance of the officers and men of H.M.S. *Alecto*, the instruments were taken ashore without delay, the concrete base was laid down, and the hut erected. By April 10 matters were sufficiently advanced to admit of full rehearsals with the remainder of the observers.

Magnificent weather prevailed during the stay of the expedition at Fundium, so that the adjustments of the instruments were made without any difficulty. The sun was not obscured by clouds on any of the thirteen days preceding the eclipse, near the time of day at which the eclipse took place, and only on a few days was there a slight haze.

The temperature in the early afternoon was usually about 90° F.

On the day of the eclipse the sky was a little more hazy than on previous days, but, on the whole, the conditions of observation were excellent.

The dismantling of the instruments was commenced immediately after the eclipse, and by the following evening everything was safely on board H.M.S. *Alecto*. On April 18 the expedition left Fundium and arrived at Bathurst next day. As the return mail steamer did not leave Bathurst for a considerable time, H.M.S. *Blonde* was kindly placed at the disposal of the expedition by the Admiralty and conveyed the party to Grand Canary, whence, after several days' delay, the passage to England was completed by the s.s. *Mequinez*.

The success of the expedition was in great measure due to the generous assistance rendered by the Admiralty in granting the use of H.M.S. *Alecto*. As there were no means of direct communication with Fundium except by a man-of-war, the expedition would otherwise have been almost impossible, and it would be difficult to over-estimate the value of the skilled help which thus became available. The subsequent grant of H.M.S. *Blonde* prevented the necessity of the expedition remaining without adequate accommodation in an unhealthy climate some two or three weeks after the work was done.

Thanks are also due to the French Government for the facilities afforded to the observers for landing in French territory; to the African Steamship Company for a material reduction of passage money; and for help in other ways to R. B. LLEWELLYN, C.M.G., the administrator at Bathurst, and M. VICTOR ALLYS, the Administrator at Fundium.

Personnel.

The general arrangements for the expedition were made by a Joint Committee of the Royal Society, the Royal Astronomical Society, and the Solar Physics Committee.

Quartermaster HALLETT, H.M.S. *Alecto*, acted as general timekeeper for the expedition, and for the detailed time records required for the prismatic camera, Lieutenant SHIPTON, R.N., gave invaluable aid. In the absence of mechanical contrivances for making the exposures, Chief Artificer MILLIGAN performed the duties entrusted to him as perfectly as could have been desired. To these, as well as to the ships' carpenters and others kindly placed at the disposal of the expedition by Lieutenant-Commander LANG, R.N., who himself did everything possible to ensure the success of the work, the best thanks of all friends of science are due.

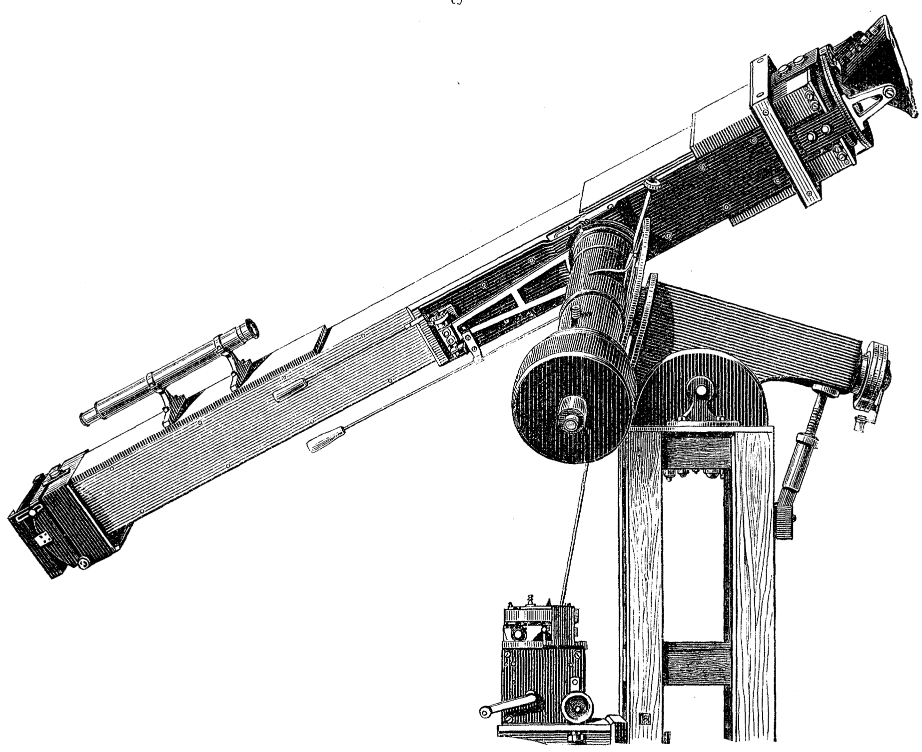
T. B. MACAULAY, of the Bathurst police force, was attached to the expedition as interpreter, and accompanied the observers to Fundium.

The Instrument Employed.

The 6-inch prismatic camera employed in Africa has a focal length of 7 feet 6 inches, and the spectrum obtained is about 2 inches long from F to K. Rings corresponding to the inner corona are about seven-eighths of an inch in diameter.

The object glass and prism, with the square tube to which they were attached, were kindly lent for the occasion by the Department of Science and Art, and the equatorial mounting was that of Professor LOCKYER'S 6-inch Cooke refractor. The tube is a strong mahogany one, square in section, and it was attached to the declination axis by means of a suitable iron plate. In order to reduce the weight of the instrumental equipment, the heavy iron pillar of the equatorial was replaced by a rough wooden stand which was filled up with concrete after being placed in position. Provision was made for the clock bracket and fine adjustments of the polar axis, and the whole arrangement was quite satisfactory.

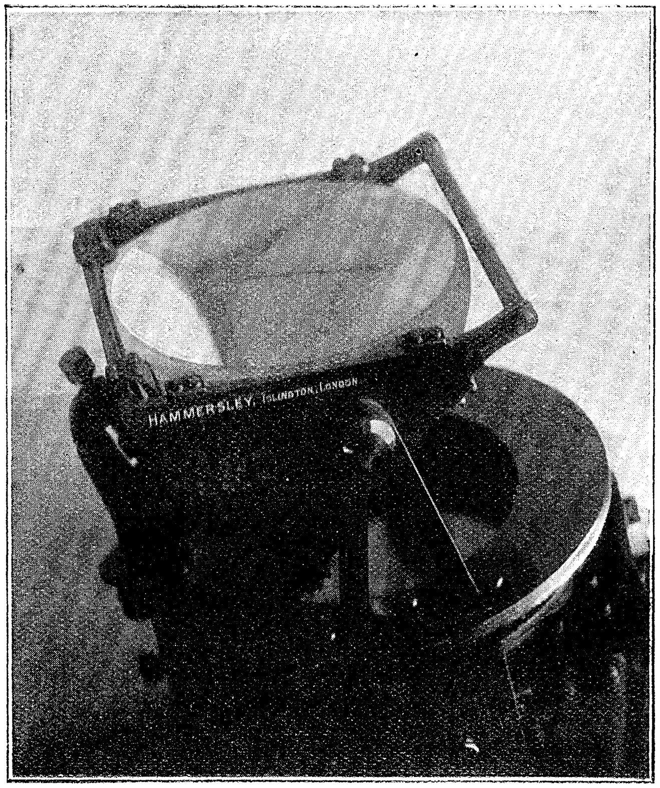
Fig. 1.



Prismatic Camera mounted on equatorial stand.

Fig. 1 represents the instrument as adjusted for use in latitude 14° 3′ N. When actually in use, the camera was steadied by a stiff wooden rod screwed to the end of the tube, and bearing on the end of the declination axis; this did not interfere with the driving gear and materially contributed to the successful results, as on account of the great weight of the prism it was necessary to bring a large part of the tube forward to the eye end. The brass cap which protected the camera from light other than that which passed through the prism and object glass, is not shown in the diagram. The details of the attachment of the prism to the object glass cell is shown in fig. 2; provision is made for adjustment to minimum deviation and for rotating the prism and clamping it in any desired position.

Fig. 2.



Details of prism mounting.

The whole instrument worked very satisfactorily, except for a slight backlash in the driving screw, which could not be corrected. On a few of the plates there is evidence of a trail of the spectrum during the exposure, in consequence of this defect, and this trail seems to be partly answerable for the absence of some of the fainter details from some of the negatives. No trouble was experienced with the driving clock.

The observatory provided for the instrument was 13 feet square, and 6 feet high, with a gable roof 4 feet in height. It consisted of a rough wooden framework, which had been completely prepared and marked before leaving England, covered with Willesden water-proof canvas. A portion of the covering of the roof was arranged so that it could be readily opened to admit of observations. The hut was very easily erected and it satisfied all requirements at a very small cost.

Conditions of the Eclipse in Africa.

The results obtained with the prismatic camera will vary in detail according to the conditions of eclipse, and it is therefore desirable to indicate the conditions obtaining in 1893.

At the African station, the apparent diameter of the sun and moon were respectively 31′ 55″·4 and 33′ 35″·9 ; the altitude at the time of eclipse was about 53°. The first contact, according to the 'Nautical Almanac' Circular, took place at an angle of about 130°, reckoned from the North point towards the West, and the last contact at an angle of 57° East of the North point. Hence, at the commencement of totality the contact would occur about 60° East of the North point, and at the end of totality about 128° W.

A calculation for the relative movement of the moon and sun during totality gives 0″·37 per second. On this relative movement depends the length of time during which the chromosphere will be visible after the beginning and before the end of totality; thus, if the chromosphere were 5″ in depth, it would have been visible for about 13 seconds on this particular occasion. The apparent depth of the chromosphere seen at the commencement of totality will be diminishing at the rate of 0″·37 per second, while that seen near the end of totality, on the opposite limb, will be increasing at the same rate. The spectroscopic appearances in successive photographs vary accordingly.

The duration of totality calculated for a place very near the selected station was 4 minutes 12·4 seconds ('Nautical Almanac' Circular, No. 14). As measured by M. Coculesco, a member of the French Expedition at Fundium, who was specially occupied with this question, the duration was 4 minutes 11 seconds.*

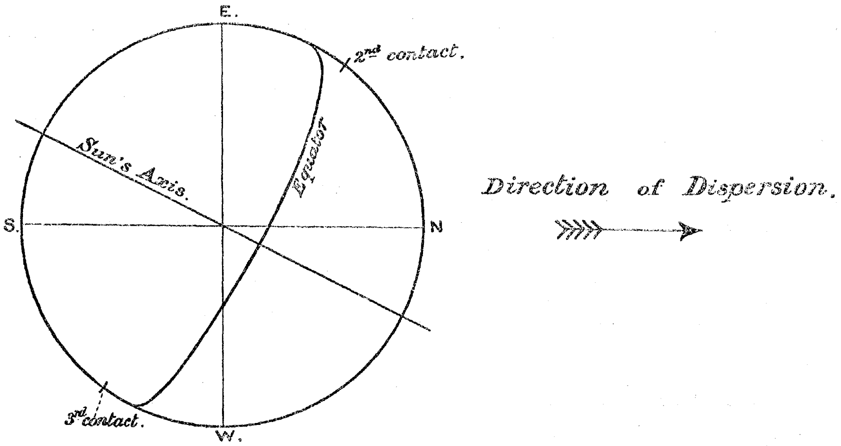
A consideration of the conditions of the eclipse indicated that on the whole the best position for the prism was that giving the dispersion in a North and South line; so long as the direction of dispersion is not nearly tangential to the sun at the points of contact, it matters little what is its direction as regards the photographs taken during totality. For the photographs out of totality, where the object is to study the phenomena at the cusps, the direction of dispersion must be such that the spectra of the two cusps are not superposed, and, if other circumstances permit, the best position of dispersion would be perpendicular to the line joining the cusps.

With an equatorially mounted prismatic camera, the position of the prism giving dispersion in a North and South line is by far the most convenient for practically working the instrument, as the deviation of the prism can be readily corrected by a movement in declination alone, and photographs of stellar spectra can be taken for focussing purposes. Hence, for the sake of greater simplicity in working, it was decided to work with a North and South dispersion, although this involved a sacrifice

* 'Comptes Rendus,' 1893, vol. 116, p. 1238.

of the phenomena appearing at one of the cusps in the photographs taken shortly after the end of totality.

Fig. 3.



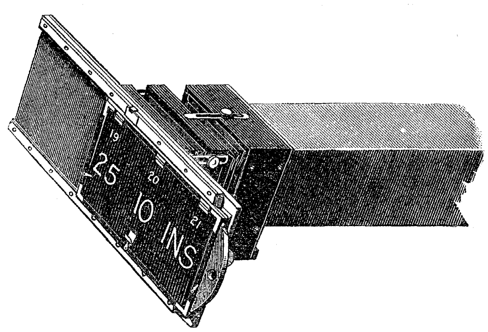
Showing position of sun's axis and equator, April 16, 1893.

Fig. 3 shows the position of the sun's poles and equator in relation to the direction of dispersion.

The Dark Slides Used.

The construction of the camera and dark slides, or plate-holders, was based on the plan devised and adopted by Professor LOCKYER for the large pictures of the corona, which he hoped to obtain in the West Indies in 1886. Fig. 4 will make them readily understood. The slides are about 13 inches in length by 7 inches broad, and have 3 compartments, each taking a plate 6 inches by 4 inches.

Fig. 4.



Details of dark slide employed in West Africa.

The camera at the end of the long wooden tube has an opening 6 inches square, and a rectangular frame 24 inches long, with a central aperture 6 inches by 4 inches, and provided with grooves to take the slides, was symmetrically attached to it. A dark slide being placed in the frame, so that the first compartment was opposite the middle of the telescope tube, the shutter was then opened to its full extent, and an exposure made; the plate in the second compartment was next brought to the middle of the frame, by pushing the slide along, and also exposed; again, by moving the slide along, the third plate was brought into position and exposed, after which the shutter was closed and the slide withdrawn. During the exposure of any one of the three plates in a slide, the other two were protected from light by the rectangular frame.

The upper edge of each dark slide was notched in three places, corresponding to the positions of the three plates which it contained, and, as each plate came to the proper position for exposure, as the slide was pushed along, a spring catch automatically dropped into its place.

Upon the back of each dark slide six numbers were painted in clear white figures. A small series of numbers corresponded to the numbering of the 30 plates to be exposed during the eclipse, and a larger series indicated the exposures to be given to each plate, so that it was unnecessary to refer to any list.

These time-saving devices are of the highest importance in eclipse work, and too much attention cannot be given to them. The arrangements in West Africa worked admirably, and it was possible to change from one plate to another in about a second when a slide was once inserted, and to change the whole slide in 5 seconds. Longer intervals, however, were allowed to elapse between the exposures, in order that the instrument might steady itself, and to correct the backlash of the driving screw.

Method of Focussing.

The instrument was focussed by photographing the spectra of some of the brighter stars. This is the only satisfactory method of focussing the prismatic camera, as rays from a star fall on the prism under exactly the same conditions as those from the eclipsed sun. If a slit and collimator be employed, identical conditions can only be obtained when the collimator is perfectly achromatic and absolutely adjusted for parallel rays.

From C to the extreme ultra-violet the focus is sufficiently constant with the Henry lens, to enable the use of a swing back to be dispensed with, and this is an immense advantage in work with the prismatic camera, for the reason that opposite sides of the rings of light corresponding to the various radiations will be equally well in focus.

The Plates Employed.

There was a little uncertainty with regard to the kind of plates which would be most suitable in the climate of West Africa, and four different commercial brands were therefore taken out, namely :—

MAWSON and SWAN'S "Stellar" plates.
EDWARDS' isochromatic plates.
Ilford isochromatic plates.
Ilford special rapid plates.

These were tested on the spot and all were found very satisfactory. Hence, some of each were employed for the work during the eclipse.

The plates were all placed in the dark slides and the films carefully numbered with pencil on the evening preceding the eclipse.

Since the isochromatic plates appear to answer as well for the blue and violet as the ordinary ones, while giving also information as to the green and yellow, it may be desirable to employ them exclusively in future.

Exposure of the Plates.

As the instrument was not provided with an exposing shutter, the exposures were made by covering and uncovering the prism with a piece of thick card. In this part of the work I was assisted by Lieutenant SHIPTON, R.N., and Chief Artificer MILLIGAN, of H.M.S. *Alecto*, and the following plan was adopted after numerous rehearsals: The dark slide being placed in proper order on a packing case close to the camera, one was inserted and the figures indicating the time of the exposure were noted, the prism being meanwhile covered; my calling out of the time of exposure was the signal for Mr. MILLIGAN to remove the card and for Lieutenant SHIPTON to commence counting the number of seconds announced, at the termination of which he gave the signal "over," the prism was covered and the dark slide moved on for the next plate. In the case of the "instantaneous" exposures, "snap" was called, the card removed for a moment by Mr. MILLIGAN, and the time noted by Lieutenant SHIPTON. After rehearsals the arrangements worked without a hitch.

A pendulum clock had been provided for recording the times, but for some reason, probably from the sand getting among the gearing, it ceased to work satisfactorily on the day of the eclipse, and a navigator's deck-watch was used in its place.

As very little idea could be formed of the length of exposure required to give the best results with this instrument, the exposures were arranged by Professor LOCKYER in a series which was repeated three times during totality. Thus, in case one particular exposure was found better than the others a good record at different stages of the eclipse would be secured. As will be seen by reference to the table on page 566, the actual exposures in the series were instantaneous, 5 seconds, 25 seconds, and 10 seconds.

Near the middle of totality a specially long exposure of 40 seconds was interpolated with the object of photographing the coronal spectrum free from admixture with the spectrum of the chromosphere.

In addition it was very important to attempt to secure records of the phenomena as nearly as possible at the beginning and end of totality. For this reason the series of exposures to which reference has been made were not commenced until an instantaneous exposure had been made, and after they were completed four more plates were taken with short exposures, in the hope that one of them might be exposed within the two seconds preceding the end, the determination of the end of totality being less certain than of the beginning.

A similar arrangement of exposures was made in the case of the photographs taken out of totality, the series in this case being 8 seconds, 2 seconds, and instantaneous. The spectrum was observed on the ground glass screen between the exposures, and seeing the great illumination of the field, I took upon myself at the last moment the responsibility of a small departure from the table drawn up and substituted two instantaneous exposures for the 2 and 8 seconds in Photographs Nos. 5 and 6, fearing that the longer exposures would fog the plates.

Plates Obtained.

A complete list of the photographs taken is given in the appended table. Column 1 contains reference numbers to the photographic plates; column 2 the brand of plate employed; column 3 the times of beginning and ending each exposure, as recorded by a deck-watch; and column 4 the amounts of exposure, "Inst." indicating an exposure given as quickly as possible by hand.

TABLE of Exposures.

No.	Kind of plate.	Times by deck watch. hrs.	mins.	secs.	Exposure.	Remarks.
1	EDWARDS' Isoch.	2	17	20	Inst.	About $6\frac{1}{2}$ mins. before totality
2	,, ,,	2	17	50·52	2 secs.	,, 6 ,, ,, ,,
3	,, ,,	2	18	21·29	8 ,,	,, $5\frac{1}{2}$,, ,, ,,
4	,, ,,	2	18	55	Inst.	,, 5 ,, ,, ,,
5	,, ,,	2	20	55	,,	,, 3 ,, ,, ,,
6	,, ,,	2	23	19	,,	,, $\frac{1}{2}$,, ,, ,,
7	MAWSON	2	23	58	,,	First photo. during totality.
8	,,	2	24	0	,,	
9	,,	2	24	6·11	5 secs.	
10	,,	2	24	21·46	25 ,,	
11	,,	2	24	48·58	10 ,,	
12	,,	2	25	2	Inst.	
13	,,	2	25	14·19	5 secs.	
14	,,	2	25	24·49	25 ,,	
15	,,	2	25	51·61	10 ,,	About mid-eclipse
16	EDWARDS' Isoch.	2	26	10	Inst.	
17	,, ,,	2	26	12·52	40 secs.	
18	,, ,,	2	26	55·60	5 ,,	
19	MAWSON	2	27	10·35	25 ,,	
20	,,	2	27	38·48	10 ,,	
21	,,	2	27	50	Inst.	Last photo. in totality
22	ILFORD, Isoch.	2	28	3·8	5 secs.	3 secs. after totality
23	,, ,,	2	28	10	Inst.	10 ,, ,, ,,
24	,, ,,	2	28	11	,,	11 ,, ,, ,,
25	ILFORD, Special	2	28	41·49	8 secs.	41 ,, ,, ,,
26	,, ,,	2	29	41·43	2 ,,	1 min. 41 secs. after totality
27	,, ,,	2	30	42	Inst.	2 mins. 42 ,, ,, ,,
28	EDWARDS' Isoch.	2	31	42·50	8 secs.	3 ,, 42 ,, ,, ,,
29	,, ,,	2	32	42·44	2 ,,	4 ,, 42 ,, ,, ,,
30	,, ,,	2	33	42	Inst.	5 ,, 42 ,, ,, ,,

The recorded times are not to be taken as the true local times at which the exposures were made, as the error of the watch was not precisely known, and the object was simply to note the durations of the exposures and the intervals elapsing between them. No attempt was made to determine the exact moments of commencement and end of totality, but the photographs taken after totality enable the end to be approximately determined from the measured width of photosphere uneclipsed. The end of totality, reckoned by the deck-watch as determined in this way, was as follows :—

	h.	m.	s.
From photograph 22	2	28	1
,, ,, 23	2	28	2
,, ,, 24	2	28	0
Mean.	2	28	1

Taking the duration to be 252 seconds, as calculated, the commencement of totality would occur at 2 hours 23 minutes 49 seconds, watch time. Accepting these times, Photograph No. 7 would thus be taken 9 seconds after the beginning of totality, and No. 21, 11 seconds before the end. The appearances on the Plates, however, seem to indicate that these intervals should be more nearly equal, and it would probably be no great error to suppose that totality commenced at 2 hours 23 minutes 48 seconds, and ended at 2 hours 28 minutes 0 seconds, by the deck-watch. The delay in commencing the photographs at the beginning of totality was occasioned by an error in the signal agreed upon for the whole party, so that Photographs Nos. 22, 23, and 24, some of which should have been taken before the end of totality, according to the table drawn up, were not taken until the sun had re-appeared. Fortunately, these three Plates are perhaps not very much less valuable than if they had been exposed at the times arranged.

III. The Brazilian Station (Mr. Shackleton's Report).

Locality.

The station selected in Brazil as being nearest the central line and point of longest duration, was a small village on the coast called Para Curu; it is situated about 50 miles North of the important town of Ceará (Fortaleza), and as read off from the Admiralty Chart is in latitude 3° 24′ S. and longitude 39° 1′ W., the latter corresponding to a difference of 2 hours 36 minutes 4 seconds W. of Greenwich.

The expedition left Southampton on February 23rd, 1893, by the R.M.S. *Tamar*, and arrived at Pernambuco on March 11th; here everything was more or less in disorder on account of the insurrection at Rio de Janeiro, and after nearly a week's delay with Custom House officialism, a start was made by a small coasting steamer, the s.s. *San Francisco*, which arrived at Ceará in six days. The instruments were again disembarked and lay in a store for about a week, until a steamer was ready to proceed northwards; this was the s.s. *Oriente*, the owners of which kindly consented for her to put into the bay at Parazinho and land the eclipse party. Arriving here on March 30th, the baggage was got on shore by means of surf rafts or catamarans, but no help was forthcoming from the natives until two days later, as they were celebrating Easter festival. During this forced idleness the time was spent in procuring a suitable site at Para Curu, some $1\frac{1}{2}$ miles away, and at length a clearing on an eminence was obtained which had a good sea horizon to the north, the observing station being south of the line. To this place the baggage was removed on April 3rd by the aid of bullock wagons, and just a week before the day of the eclipse, huts had been built and the instruments adjusted. The weather continued very fine until within three days previous to the eclipse, during which rehearsals were gone through to get accustomed to the work, and also to find out the minimum time which could be allowed with safety to move the dark slides from one plate to another, and also to effect a complete change of slides; this was found to be 2 and 8 seconds respectively

After this the sky was continually obscured by clouds and rain fell heavily; this seemed likely to persist, but no rain fell on the morning of the eclipse, and fortunately about half-an-hour before totality commenced, the sky began to clear and remained perfectly so during the whole time of total eclipse.

As soon as the photographs had been taken, the dark slides were removed to a place of safety and the huts were covered over and made fast. This had scarcely been accomplished, when a tropical downpour followed, which continued during the remaining part of the day. Similar weather was experienced by a party of astronomers from Rio de Janeiro, who had their station at a village some miles distant, and who paid a visit to Para Curu, but the compliment could not be returned in consequence of the difficulty and unfamiliarity with bush travelling, besides the fatigue experienced with the thermometer registering 96° in the shade during the day and 88° during the night. The following three days were spent in taking the instruments to pieces and packing up, after which there was nothing to be done but to wait for the steamer which was to call on its way south; this proved to be the s.s. *Colombo,* which put in appearance seven days after the eclipse. The instruments were again got aboard by the rafts, and passage was then taken back to Ceará, where the baggage was shipped on a cargo steamer bound for Liverpool, so as to prevent the many transhipments which would otherwise have been necessary. After a few days' waiting, passage was again taken to Pernambuco by the s.s. *Brazil;* thence the return voyage to England was completed by the R.M.S. *Trent.*

Personnel.

In the absence of such skilled assistance as could be offered by a man-of-war, most of the work was of necessity performed by myself, but thanks are due to Sir J. B. STONE for photographing the instruments; to M. OLSEN (photographer at Ceará), for use of dark room; and to the interpreter, Mr. A. FURLEY (Ceará Harbour Works), for assistance in erection of huts and instruments.

The Brazilian Instrument.

The prismatic camera employed in Brazil was simply a large photographic spectroscope deprived of its collimator, mounted on an iron table. The dispersive train consisted of two prisms, each having a refracting angle of 60° and a clear aperture of 3 inches. The object glass was a Dallmeyer portrait lens, 5 D, aperture 3·25 inches, focal length 19 inches.

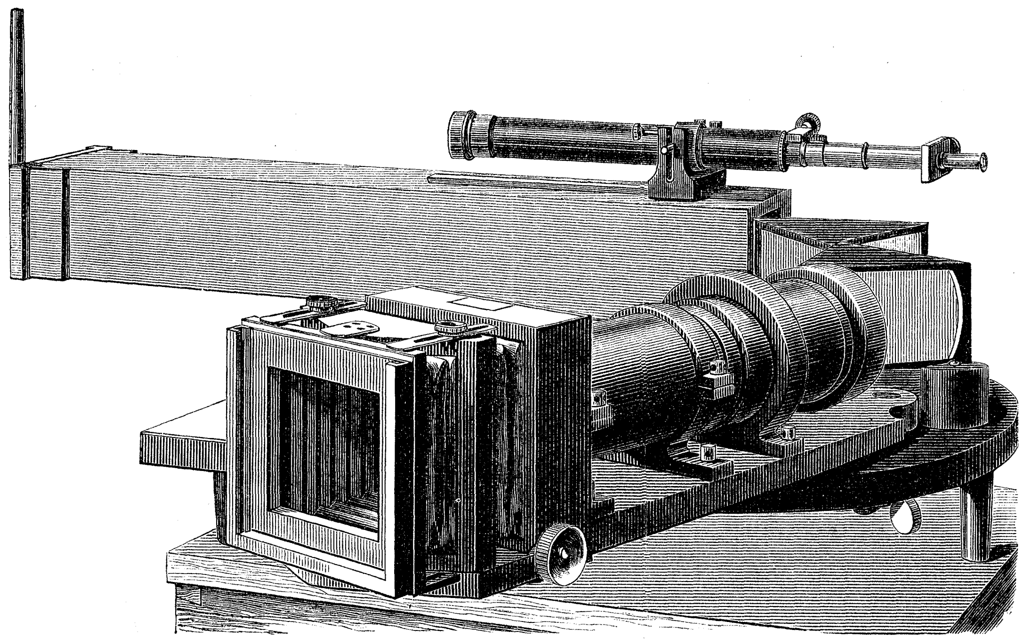
As explained in the report by Mr. FOWLER, the direction of the refracting edges of the prisms has its maximum efficiency defined by the position-angle of the cusps, but with this form of prismatic camera the faces of prisms were of necessity vertical, and therefore the direction of dispersion could not be controlled; fortunately, however, it so happened that the cusps were favourably situated.

The diameters of the moon and sun were such that this camera gave images of ·183 inch and ·176 inch respectively. The length of the spectrum given by the combination was 2·5 inches from D_3 to K or 1·65 inches from F (H_β) to K.

The light from the sun was reflected on to the prisms from the mirror of a 12-inch Cooke siderostat, and to keep any extraneous light from entering the camera, a wooden tube was put in the place ordinarily occupied by the collimator; at the end of the tube was a shutter which could be closed and opened from the camera end with a cord, and by means of this the length of exposures was regulated.

On the top of the wooden tube was placed a small telescope to serve as finder, it being directed to a portion of the mirror not utilized by the prismatic camera; the arrangement is shown in the accompanying figure.

Fig. 5.



Prismatic camera used in Brazil.

A small hut to enclose the siderostat was erected, and, with the exception of one side and the front, which were made of canvas on wooden frames (so as to be easily moved), it was built of wood. The fall for the clock weights was made by erecting a sort of gallows behind the hut, over which the clock cord was directed by pulleys. About ten feet away to the North, the hut to hold the prismatic camera was built, this was also small, being only sufficiently large to hold the instrument, and constructed in the same way as the one described above, the observer taking his place outside.

The siderostat was set down on a firm concrete base and adjusted for latitude by watching the image of a star or the sun with a theodolite set in a meridian line North of the mirror, and seeing that it did not leave the cross wires; then the spectroscope was placed on a large packing case, loaded with gravel for rigidity, with its collimator in a North and South line directed to the centre of the mirror, and the prisms set to minimum deviation for F (Hβ).

Conditions of Eclipse.

At the Brazilian station the diameters of the sun and moon were 31′ 55″·4 and 36′ 6″·6 respectively; this difference of diameters gave a duration of 4 minutes 43 seconds, hence the relative movement was at the rate of ·253″ per second.

The first contact took place at an angle of 136° W. of the North point, and the last contact at an angle of 45° E. of the North point; therefore the direction of the moon's motion cut the North and South line of the sun very nearly at an angle of 45°.

The local mean times of commencement and ending of totality were 11 hours 40 minutes 51 seconds and 11 hours 45 minutes 34 seconds respectively, giving a duration of 4 minutes 43 seconds, and the altitude of the sun was 76°.

The Greenwich mean time of totality was 2 hours 17 minutes, thus preceding the total phase at the African station by 1 hour 20 minutes, and following that of the Chilian station by 1 hour 10 minutes.

Dark Slides Employed.

Three dark slides were provided; they were made so as to travel up and down by means of a rack and pinion, in a frame fitting into the back of the camera. Each slide had eight compartments for plates ($4\frac{1}{4} \times 1\frac{3}{4}''$), and the plates were successively brought into position by raising the slide (fig. 6).

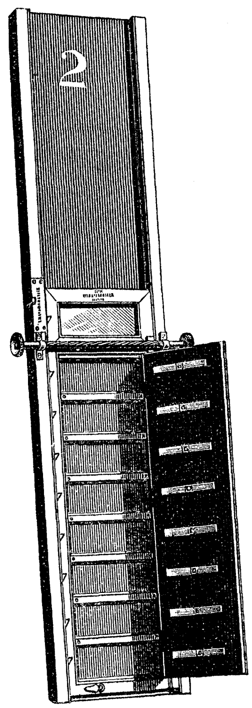
Corresponding to each compartment there was a notch at the side, which indicated the exact place for the plate when a spring detent in the frame fell into the notch, the detent being so arranged as to allow the slide to move only in one direction.

The number of each slide was cut in deep Roman numerals, so that it could be known by touch when it was in the velvet bag, without bringing it into the light, for it was necessary to know which one was being dealt with, as they contained different kinds of plates.

Method of Focussing.

The collimation for parallel rays had been effected before leaving England, but this was again verified, and trial photographs were then taken till an excellent focussed spectrum was obtained from D to beyond K in the ultra-violet. To obtain the same conditions as would hold during the eclipse, the collimator was then removed and an attempt made to photograph the spectrum of a star (Arcturus); as perhaps the best way of ensuring good definition from one end of the spectrum to the other is to get the spectrum of a star in focus, for collimation can only be effected over a small region, unless the collimating lens is perfectly achromatic. To make the image of the star to travel in a direction parallel of the edges of the prisms (in order to give breadth of the spectrum) it was necessary to throw the polar-axis slightly out of adjustment and to keep the clock going to star rate by means of the fine adjustment in right ascension; after several trials a photograph was obtained which showed the spectrum of the star,

Fig. 6.



Dark slide employed in Brazil.

but only between $H\beta$ and $H\gamma$, and this seemed to be fairly well in focus. From this time up to the day of the eclipse there was no possibility of trying this again, so that the focus had to be taken as final. It so happened, however, that the spectrum was in focus between $\lambda\lambda$ 58 and 44 and again between $\lambda\lambda$ 37 and 35. The same thing appears to have occurred, only more seriously, when the instrument was previously used during the eclipse of 1883.

Plates Employed.

As stated in Mr. FOWLER's report, there was some uncertainty as to the kind of plate best suited for this work, and for that reason similar brands to those used by him were employed with this instrument, except that of the isochromatic; those made by EDWARDS were solely used, the other makes proving (in the preliminary trials) not to be as suitable under the climatic conditions. About twelve of the plates were backed with pitch dissolved in benzene during the night preceding the eclipse; the remaining twelve were left untouched, and do not appear to have suffered in any way from the effects of halation.

Exposure of the Plates.

All the operations for exposing the plates were performed by myself, durations being allowed according to a table drawn up by Professor LOCKYER. The plates were successively brought into position with the rack and pinion of the dark slide, and the length of exposure was regulated by means of the shutter in front of the prisms.

About the beginning and end of totality the exposures were short, whilst at mid-eclipse the longest duration was given, followed by one of instantaneous exposure. Also at successive intervals similar exposures were made, as shown by the appended tables :—

No.	Exposures.	No.
5	Instantaneous	9
6	5 seconds	10
7	30 ,,	11

No.	Exposures.	No.
6	5 seconds	15
7	30 ,,	16
8	15 ,,	17
9	Instantaneous	18
10	5 seconds	19

Thus not only are individual plates comparable, by a reason of like exposures, but also a series of them.

The Plates Obtained.

A list of the photographs taken is given in the accompanying table. The first column gives the numbers of the photographs for use in subsequent references, and indicates also the order in which the photographs were taken. The second column indicates the kind of photographic plate, while the third column indicates the amount of exposure, as reckoned by a watch; "instantaneous" means that the shutter was opened and closed again as quickly as possible. The intervals elapsing between the exposures of successive plates are shown in Column 4. These could not be reckoned directly by the watch, but from previous experience and the summation of times of exposure deducted from the total duration they were indirectly estimated. When taken in conjunction with the lengths of exposure, the intervals enable us to form an estimate of the interval from the beginning or end of totality at which any one of the plates was taken. This method of recording the times was adopted because no time-keeper was available. Photograph No. 2 was probably taken within two seconds after the commencement of totality, while the end of totality took place between the exposure of Photographs Nos. 18 and 19.

No.	Kind of plate.	Exposure.	Interval of change.	Remarks.
1	MAWSON	Inst.	$\frac{1}{2}$ min.	
2	,,	2 secs.	2 secs.	Commencement of totality
3	,,	8 ,,	2 ,,	
4	,, (Stellar)	Inst.	2 ,,	
5	,, ,,	,,	2 ,,	
6	,,	5 secs.	2 ,,	
7	,,	30 ,,	2 ,,	
8	,,	15 ,,	2 ,,	
9	,, ,,	Inst.	2 ,,	
10	Isochromatic (EDWARDS)	5 secs.	2 ,,	
11	,, ,,	30 ,,	2 ,,	
12	,, ,,	60 ,,	2 ,,	Middle of eclipse
13	,, ,,	Inst.	2 ,,	
14	,, ,,	30 secs.	2 ,,	
15	,, ,,	5 ,,	2 ,,	
16	MAWSON	30 ,,	10 ,,	
17	,,	15 ,,	2 ,,	
18	,, (Stellar)	Inst.	2 ,,	Last photo. in totality
19	,, ,,	5 secs.	2 ,,	After totality
20	,, ,,	Inst.	5 ,,	,, ,,
21	,,	,,	10 ,,	,, ,,
22	,,	8 secs.	20 ,,	,, ,,
23	,,	Inst.	2 ,,	,, ,,
24	,,	,,	..	,, ,,

IV. DESCRIPTION OF THE AFRICAN PHOTOGRAPHS.

Photographs near Beginning of Totality.

From what has been stated with respect to the conditions of eclipse, it is clear that at the commencement of totality an arc of chromosphere and its associated prominences would be visible in the north-east quadrant. In other parts of the sun's edge, the chromosphere was hidden by the moon, but several prominences were large enough to show their outlying parts, with the result that the photographs exhibit nearly complete rings in the radiations common to chromosphere and prominences. Negative No. 7, taken with an instantaneous exposure about 10 seconds after the commencement of totality, is reproduced in Plate 11; as the photographic plate was not isochromatic, the spectrum only extends to F at the less refrangible end. The principal lines, or rather portions of rings, are obviously due to the H and K radiations of calcium and hydrogen radiations. The bright arc on the right is H_δ, and the two very prominent rings near the violet end are H and K.

The photograph shows very distinctly the variation of spectrum in passing from one prominence or chromospheric region to another. One small prominence is specially remarkable for its complex spectrum, and there is nearly every gradation between this and prominences which show practically nothing but H and K. The forms of the prominences themselves are very clearly depicted, and it will be seen that the scale is sufficiently large to reduce confusion of images to a minimum. The general appearances on the photograph correspond very closely with those seen at the beginning of totality by RESPIGHI in 1871, and by RANYARD in 1878.

Negative No. 8, taken 2 seconds later, is hardly distinguishable from No. 7. In both plates the corona is represented chiefly by what appears to be continuous spectrum. As was to be expected from the projection consequent on the direction of dispersion, this continuous spectrum is brightest at the eastern and western limbs, and it is brighter on the eastern than the western side, this region of greater intensity corresponding to a lower part of the corona. Besides the continuous spectrum, however, there are a few feeble arcs, not seen in the reproduction, representing true coronal radiations; these are quite distinct from the chromospheric arcs.

Photographs about Mid-eclipse.

The arc of chromosphere, seen in Photographs Nos. 7 and 8, was covered by the moon when the next plate was exposed, but the associated prominences were not completely extinguished by the advancing moon until No. 17 was exposed. The upper part of the chromosphere in the south-western quadrant did not appear until No. 20 was exposed. Hence, Photographs 9–19 inclusive show no chromospheric spectrum, but they give a record of the spectra of the upper parts of numerous prominences, as well as of the spectrum of the corona.

A reproduction of Negative 17, taken on an isochromatic plate, is given in Plate 12. It will be seen that the spectra of the prominences are similar to those in No. 7, but they are simpler for the reason that the lower reaches were covered by the moon. At the extreme right in the photograph there is a feeble image of the bright group of prominences produced by the C radiation of hydrogen; as the plates are scarcely sensitive at all to the red, the image must in reality have been very intense; D_3 images of the prominences are also seen in the photographs.

The spectrum of the corona in Negatives 9–19 is to a large extent continuous, but, in addition, it is represented in some of the photographs by a nearly complete ring corresponding to the 1474 K line, and smaller portions of fainter rings.

The continuous spectrum is brightest near the photosphere, and fades out very gradually at heights depending upon the exposure and development of the plates and the wave-length of the light. The maximum intensity on the ordinary plates is about λ 450, while the isochromatic plates have another maximum about λ 560, and it is at these wave-lengths that the continuous spectrum extends furthest from the photosphere. The greatest extension is in Plates Nos. 13, 15, and 19, where it amounts to two-thirds of the sun's apparent diameter, corresponding to a height above the photosphere of nearly 600,000 miles.

From the points of maximum photographic action the continuous spectrum diminishes in height and intensity in both directions.

The 1474 ring appears on Photographs 9, 16, 17, and 18, the last three being isochromatic; its appearance on Photograph No. 9 indicates its great intensity in the lower corona. It is important to bear in mind that in successive photographs the conditions are different. Thus Photograph 9 was exposed between 18 and 23 seconds after the commencement of totality, so that at the beginning of the exposure the lowest part of the corona, in the north-east quadrant, was only about 3,000 miles from the photosphere, the relative movement of the moon when projected on the sun being about 166 miles per second. At the beginning of the exposure of Photograph 16, on the other hand, the lowest part of the corona photographed in the north-east quadrant was nearly 24,000 miles above the photosphere, and that in the south-west quadrant about 18,000 miles; in this photograph the 1474 ring is consequently brightest in the south-west quadrant. In the case of Photograph No. 17 the conditions at the beginning of the exposure were almost identical with those at the end of No. 16, but in this case the exposure was 40 seconds; at the middle of the exposure the moon's limb would be about 27,000 miles above the photosphere in the north-east quadrant, and in the south-west nearly 15,000 miles.

At the middle of the exposure of Photograph No. 18, the corresponding figures were about 31,000 and 11,000 miles.

The greatest height of the 1474 K ring occurs in No. 17, taken with a long exposure; in its brightest part it extends about 45″ above the moon's limb, corresponding to a distance of about 20,000 miles. Its intensity varies greatly, being scarcely visible in the region of the sun's poles, and brightest in the equatorial regions; the brightest parts of the ring correspond with the brightest regions in the photographs of the corona taken with the coronagraph. The ring is quite distinct from the prominence rings and is not intensified in the region of prominences, indeed there seems to be no trace of 1474 in the spectrum of any of the prominences.

In Negative No. 17, Plate 12, the 1474 ring is at the right of the photograph, just within the very broad ill-defined ring due, as shown elsewhere, to photographic causes.

Like 1474 K, the fainter coronal rings are as readily distinguished from chromosphere and prominence rings, as the latter are from the corona in an ordinary photograph, as their maximum luminosity never coincides with them; while the monochromatic images of chromosphere and prominences are sharply outlined, the true coronal rings are not thus defined. The intensities of the coronal radiations appear to diminish very rapidly in passing outwards from the sun's limb. The distribution of these rings in the African Negative No. 17 is shown by the dotted arcs in Plate 12, it being quite impossible to reproduce the rings themselves in photographic enlargements in consequence of their dimness.

Photographs taken near the end of Totality.

Two photographs, Nos. 20 and 21, were taken during the visibility of the chromosphere in the south-west quadrant just before the end of totality. No. 21, taken with an instantaneous exposure about 10 seconds before the end of totality, is reproduced in Plate 11, and it will be seen that the appearances are very similar to those photographed near the beginning of totality. The spectrum of a long arc of chromosphere and of numerous prominences are very strongly marked, and the full dimensions of the large group of prominences near the sun's south pole are at the same time revealed. This group was large enough to be visible throughout the whole of totality, but others are only visible in the photographs near the beginning and end. The spectra of the prominences are again of various degrees of complexity.

The corona is represented chiefly by continuous spectrum, but faint arcs representing coronal radiations can also be distinguished in the negatives; one, a little less refrangible than H, is sufficiently bright and defined to be seen in the reproduction of Photograph No. 21. The continuous spectrum of the corona in these photographs is brightest on the western (lower) edge, for the reason that at that part of the sun's limb the moon's edge was nearer to the photosphere than at the opposite limb, so that a brighter part of the corona was exposed.

The coronal ring corresponding to 1474 K is not seen in either No. 20 or 21, as the plates were not isochromatic.

Unfortunately, the attempt to make an exposure at the moment of third contact was not successful, for the reason already stated.

Photographs taken out of Totality.

Six photographs (Nos. 1–6) were taken before totality, and nine (Nos. 22–30) after totality.

The first five show nothing but a curved Fraunhofer spectrum, the visible crescent acting as a curved slit. No. 6 shows a similar spectrum with the addition of five short bright arcs at the cusp nearest to the north point in continuation of the dark arcs due to H_β, H_γ, H_δ, and H and K; it also shows faint impressions in H and K radiations of the prominences in the region of the sun's south pole. Photographs 27 to 30 inclusive also give nothing but a Fraunhofer spectrum, the curves being diametrically opposed to those appearing in the photographs taken before totality. Photographs Nos. 25 and 26 show in addition bright projecting arcs at H and K, H_γ, H_δ, and H_ζ.

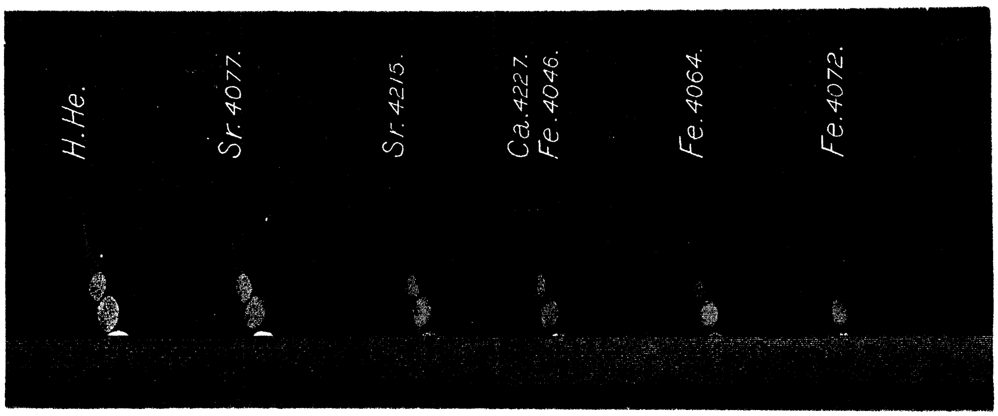
The most valuable photographs taken out of totality are Nos. 22, 23, and 24, all taken within about 12 seconds from the end of totality. During this interval the photospheric light was sufficiently reduced to exhibit the radiation spectra of the surrounding vapours.

The visible crescent of photosphere when these three photographs were taken was in the south-west quadrant, and as the dispersion was in the north and south direction, the cusp nearest to the south point was the one most favourably situated for showing bright arcs. The light of the photosphere is drawn out into a continuous band by the action of the prism, and this band is of varying intensity in consequence of the irregularities of the moon's limb, the so-called BAILY's beads being drawn out into longitudinal streaks, as was seen in a photograph taken out of totality in 1882.

In Photograph No. 22 this photospheric spectrum is crossed by bright arcs which also project some distance beyond in both directions, and no Fraunhofer lines are visible; the bright arcs corresponding to H_β, H_γ, H_δ, H, and K, H_ζ, and other ultra-violet lines of hydrogen are especially intense. The group of prominences near the south pole is also depicted in these radiations, as well as in H_α and D_3. A very large number of short bright arcs is also seen at the cusp, but these cannot be traced across the spectrum of the photosphere.

An attempt to indicate the appearances of different typical arcs is made in fig. 7, as the detail is too minute to be satisfactorily shown in a photographic reproduction. The brighter ones show great irregularities throughout their lengths, and the fainter

Fig. 7.



Appearances of bright arcs in spectrum of cusp.

ones appear only in the parts corresponding to the brightest regions. None of the arcs are brightest close to the edge of the continuous spectrum, and the faintest of them have the appearance of being detached as in the case of Fe 4072 in the diagram. In the Photograph No. 22 the spectrum of the corona is also seen; as a faint continuous one at the eastern and western edges on the illuminated sky background, and an arc corresponding to 1474 K is visible in the south-western part. A portion of this photograph is given in Plate 13. It cannot be satisfactorily reproduced in its entirety owing to the great density of the negative. The general appearances of Photographs 23 and 24 (see Plate 13) are very similar to that of No. 22, but there are several important differences in detail. The photospheric spectrum, which is of increased width in each case, shows the longitudinal dark streaks due to BAILY's beads, and they both show bright chromospheric arcs crossing the continuous spectrum, as well as bright arcs at the cusp. In No. 23, however, distinct traces of the strongest FRAUNHOFER lines are seen, especially in the ultra-violet, and they are still more plainly marked in No. 24. The bright arcs at H and K, H_γ, &c., are not quite coincident with the corresponding dark ones, but lie on the outer edges, as might be expected. The number of bright arcs at the cusp in No. 23 is very much smaller than in No. 22, and in No. 24 it is smaller still. The continuous spectrum of the corona is faintly impressed at the eastern edge, but 1474 K and other coronal radiations are not seen.

In passing outwards from totality, the bright lines at the cusp become reduced in number and intensity, while the Fraunhofer spectrum becomes more and more distinct (see Photograph No. 25, Plate 13)* up to a certain limit; after which the dark arcs become broad and ill defined.

V. DESCRIPTION OF THE BRAZILIAN PHOTOGRAPHS.

Photographs near Beginning of Totality.

Photograph No. 2, which is reproduced in Plate 12, is as near as possible the commencement of totality. It shows rings of chromosphere and prominences in positions corresponding to H and K, H_β, H_γ, H_δ, H_ζ. Near the top of the spectrum is a strip much brighter than the other parts of the spectrum; it corresponds with the central part of the chromospheric arc visible when the plate was exposed. Projecting out of this strip are many bright arcs, less refrangible than F (H_β) and more refrangible than K; between these two wave-lengths, however, in consequence of the extreme brightness of the chromosphere the photograph is considerably over-exposed, and the bright arcs are masked. As the moon advanced and covered the chromosphere, other photographs were taken which show that it was obscured at the fifth photograph; hence, knowing the interval of time between these two photographs (from table = 25 seconds) and knowing the relative motion of the moon (·253″ per second), this gives 2,850 miles as the depth of the chromosphere, a very close agreement with that calculated from the African photographs. Photographs 3, 4, and 5 are very similar to the corresponding African photographs, but they do not show so much detail.

The spectrum of the corona is represented in Photographs 2, 3, 4, and 5, by an apparently continuous spectrum, which by reason of the projection of the broad ring is brightest along the top edge of the spectrum. The maximum intensity is about λ 448, and at this point the continuous spectrum can be traced to a distance of 6′·5 above the moon's limb. At the bottom edge of the spectrum the intensity is

* It will be observed that this photograph is solarised, owing to over-exposure.

less, because the lower part of the corona was eclipsed when these photographs were taken.

Photographs about Mid-Eclipse.

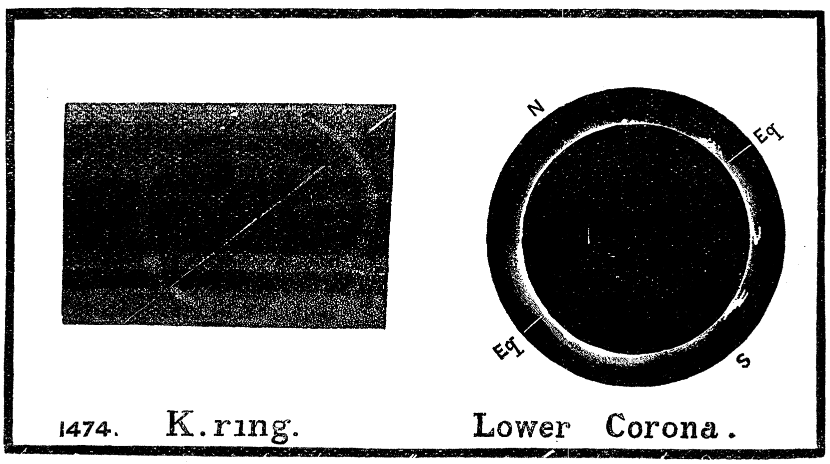
As in the case of the African series there are several of the photographs, Nos. 6 to 16, which show no chromosphere spectrum, although the spectrum of some of the larger prominences are present. Only the upper parts of such prominences are visible, and their spectra are very simple, consisting of hydrogen, helium, and the H and K radiations of calcium.

The continuous spectrum of the corona in these photographs is very similar in appearance to that described in the earlier photographs, except that in those of long exposure it extends to the considerable height of 12′ above the moon's edge.

By reason of the short focal length of the object glass used in Brazil the images of the coronal rings would be six and a quarter times brighter than those given with the African instrument, and for the same reason, together with the less dispersion, the continuous spectrum is five and a quarter times brighter.

Consequently, as will be seen on reference to the Brazilian negatives taken in mid-eclipse (Plate 12), they are remarkable for the great intensity and definition of the 1474 K-ring, which from measurements extend to a height of 2′ above the moon's edge. An enlargement of the ring as it appears in the Negative No. 12, is given in fig. 8, where it is placed alongside a reduced copy of a photograph taken

Fig. 8.



Comparison of the 1474 K-ring with the lower corona.

by SCHAEBERLE in Chili. The latter has been selected because the exposure was relatively short enough to make the lower corona thus obtained comparable with the spectrum ring at 1474 K. It will be seen that the prismatic camera has picked out the brightest parts of the corona, and where it is strongest the spectrum ring and the continuous spectrum at these points is most intense, whilst a prominence occurring at any part of the sun's limb does not appear to alter the intensity of the coronal ring at the corresponding part. Besides this principal ring we should expect to see some of the fainter ones shown on the African negatives, if their presence was not masked by the intense continuous spectrum, but there are indications of others in less actinic parts of the spectrum, which are not shown on the African plates.

Photographs about End of Totality.

The chromosphere begins to put in appearance again, but only feebly, in Photograph 16; between this and the next plate a change of slides was made, and a considerable time elapsed. In consequence of this rather large interval between the 16th and 17th exposures it is slightly difficult to estimate more than approximately the length of time the chromosphere was visible, but probably corresponds very nearly to that at the beginning of the eclipse. Photograph No. 18 was the last exposed during totality; the sun reappearing between exposing this plate and No. 19, the spectrum of the chromosphere is shown by long arcs corresponding to H_β, H_γ, H_δ, H_ζ, H_η, H_θ, some of the principal Ca and Sr lines and some He lines. The spectrum of the corona is represented by the continuous spectrum, intensified in the two strong bands at the top and bottom of the spectrum for reasons explained previously.

Photographs Out of Totality.

The first photo. out of totality was No. 1: it was given an instantaneous exposure, and a narrow band of continuous spectrum extends from one end of the plate to the other; besides this there seems to be no indications of any arcs from the prominences except those corresponding to H_β, H_γ, H_δ, H_ϵ, and K.

In this respect it is very similar to Photograph No. 22, taken at the African station.

The first photo. after totality, No. 19, was exposed for 5 seconds, probably commencing about two seconds after the sun broke out. During this time the sun was sufficiently uncovered to present a thin crescent, and the photograph shows a Fraunhofer spectrum with arcs in place of the lines observed in the ordinary way.

In consequence of the long exposure the Fraunhofer spectrum is solarised, and outside this the plate is much fogged with stray light, which was then becoming strong, but here and there, where a prominence was unusually high to show beyond the edge of the moon, and bright enough to be seen above the stray light, are a few dots from the top of a prominence, in positions corresponding to the hydrogen lines. The remaining five plates are very similar to the one described above, except that as the crescent of the sun became broader, the Fraunhofer spectrum is more ill defined.

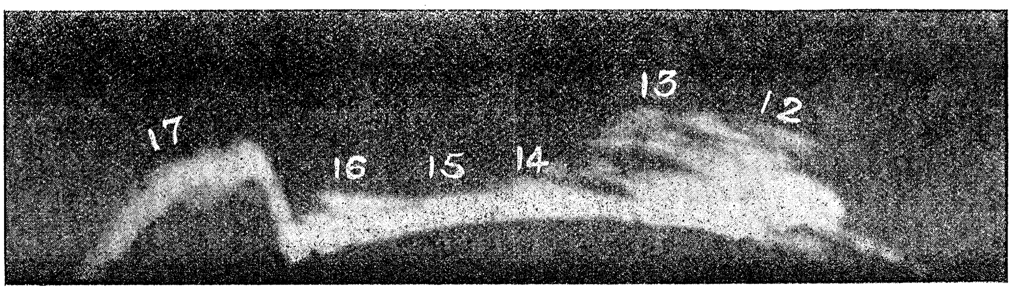
VI. Forms of the Prominences.

Monochromatic Images.

The results obtained clearly indicate that the best possible way of photographing the prominences during a total eclipse, so as to show their forms, is to secure monochromatic images of them by means of the prismatic camera. In the pictures taken with the coronagraph in the ordinary way the prominences are apt to be submerged in the intense light of the lower corona. In some of the African photographs taken with the prismatic camera the definition is very fine, and the structure can be minutely investigated by enlarging the photographs. The group of prominences near the sun's south pole shows a wealth of detail in most of the African negatives, as will be clear from the enlargement of the K image, which is reproduced in fig. 9.

By isolating the portions of the rings of prominences and chromosphere which correspond to any particular radiation, the distribution of the corresponding vapour can be represented at any phase of the eclipse; a composite photograph made up of two such isolated portions of rings, one as seen at the beginning and the other at the end of totality, indicates the distribution of the vapour throughout the chromosphere and prominences visible during the whole of totality. Fig. 10 is a copy of the K-ring, as built up from the African photographs Nos. 7 and 21, the light due to other radiations having been painted out.

Fig. 9.

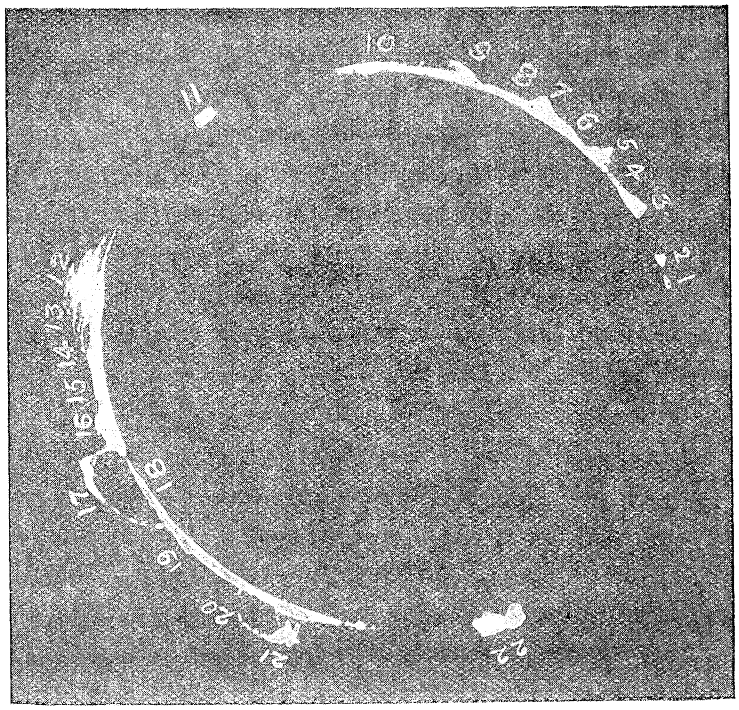


Group of prominences near sun's south pole, April 16, 1893.

The ring is not complete for the reason that some parts of the chromosphere—namely, those in the neighbourhood of the points on the sun's limb which are cut by a line perpendicular to the direction of the moon's motion—were covered by the moon during the whole of totality.

The various parts of the chromosphere and prominences have been numbered, as shown in the above diagram, for purposes of reference in the discussion of the photographs.

Fig. 10.



Chromosphere and prominences depicted in the K radiation of calcium.

Forms in Different Radiations.

Rings corresponding to various radiations can be isolated in the way indicated, and compared with each other. This has been done for H_β and, so far as it goes, it resembles the K ring, but some of the prominences depicted by K are not shown in H_β light. In the case of the metallic prominences, the images formed by the hydrogen radiations very closely resemble those formed by H and K, but they do not reach to so great a height. In the case of large prominences, such as that near the south pole, the hydrogen images are feeble and show only very small parts of those depicted in H and K light, although H and K are quite as intense as in the metallic prominences.

The images produced by the radiations of helium are similar to those given by hydrogen, but they are smaller and less intense.

Effects of Movement.

The forms of monochromatic images of the prominences may be produced in part by the movement in the line of sight of the vapours which give rise to them. Regions in which the vapours are approaching the earth will be displaced to the more refrangible side of their true positions with respect to the sun's limb, and in the case of receding vapours there would be displacements towards the less refrangible end. Such distortions can be determined, if they exist, by comparing the monochromatic images with those photographed at the same time with the coronagraph. For this purpose a photograph of the eclipsed sun was enlarged to exactly the same size as the K ring shown in fig. 10, and the comparison could be made very exactly by fitting a negative of one to a positive of the other. No differences of form, however, could be detected, so that the velocities in the line of sight must have been comparatively small. Movements across the line of sight, that is normal to the photosphere, would not affect the forms of the monochromatic images of the prominences.

PART II.—DISCUSSION OF THE OBSERVATIONS.

VII. The Interpretation of the Photographs.

Having now given a description of the phenomena actually photographed, I proceed to consider how we are to justly interpret them. For this purpose it is necessary first to deal generally with the results as contrasted with those given by slit-spectroscopes, in which an object glass is employed to form an image of the eclipsed sun upon the slit, and then to consider the phenomena which might be expected under the most probable conditions of solar structure.

Comparison of the results to be expected from Slit and Slitless Spectroscopes.

The considerations which led me, in 1871, to employ a spectroscope without collimator may be briefly stated. If in an ordinary spectroscope, the straight slit be replaced by a circular one, bright rings replace the bright lines which are ordinarily seen in radiation spectra, and since in the solar surroundings we have chiefly to deal with radiation phenomena, the chromosphere and corona themselves can be used during an eclipse as ring slits, and on account of their distance, a collimating lens can be dispensed with.

In the report on the eclipse of 1875, by Dr. Schuster and myself, the principles of the method, as applying to photographs taken during totality, were stated as follows :*

"Supposing that the corona and chromosphere only send out the same homogeneous light, one image only will appear on the sensitive plate, the only effect of the prism being to displace the image. As far as the protuberances are concerned we know they give a spectrum of bright lines, and we expect, therefore, to find on the plate each protuberance represented as many times as it contains lines in the photographic region. The different protuberances would be arranged in a circle round the sun, and

* 'Phil. Trans.,' 1878, Part 1, p. 139.

these circles would overlap or not, according to the dispersive power of the prism and the difference in refrangibility of the lines. . . . If the corona gives a series of bright lines we shall find a series of outlines on the photographs similar to that corresponding to the protuberances. . . . If we find that part of the corona gives a continuous spectrum, that part alone will be drawn out into a band."

To this it may be added, that successive photographs will differ on account of the difference of phase. One part of the chromosphere will be visible at the beginning of totality, and another part at the end. The smaller prominences visible at the beginning of totality are subsequently eclipsed by the moon, and their spectra are consequently absent from later photographs, while a new prominence region makes its appearance. In the same way, the part of the corona the spectrum of which is photographed will vary at different phases, but only in the lower parts.

Corona.

For the discussion of the advantages of the different methods of work in the case of the corona, it is necessary to consider the possible sources of spectra which are to be found in the neighbourhood of the corona. From previous experience, the chief sources may be stated as follows :—

(*a*) Intrinsic light of the corona, giving the so-called continuous spectrum.

(*b*) Intrinsic light of the corona, giving bright lines.

(*c*) Light of the sun reflected by the solid or liquid particles in the corona.

(*d*) Light scattered by the particles in our own atmosphere, giving frequently the lines of the chromosphere and prominences.

It is evident that a slit spectroscope must integrate all these spectra, so that in discussing any particular line it is very difficult to know to which origin it should be ascribed. For example, if we suppose the corona to give a spectrum of hydrogen, the lines will be superposed upon lines of hydrogen due to the light of the prominences scattered by our atmosphere, and it would not be safe to draw any conclusion as to the presence or absence of hydrogen in the corona.

The advantages of the slit spectroscope in regard to the corona may be stated as follows :—

(1.) If the spectrum of the corona consists of a large number of lines of nearly equal intensity, the slit spectroscope will show them more clearly than the prismatic camera, for the reason that, with the latter instrument, the overlapping of the rings would have a greater tendency to give the spectrum the appearance of being continuous. With a wide slit this advantage of the slit spectroscope would be diminished.

(2.) Feeble corona lines have a greater chance to show themselves with the slit spectroscope, since it only takes account of a very small area giving continuous spectrum, while, in the prismatic camera, the continuous spectrum from adjacent parts is superposed, with the result that there is a greater tendency to masking of bright lines. The use of greater dispersion in the case of the prismatic camera would tend to remove its deficiency in this respect.

(3.) The slit spectroscope will give well-defined spectra, due to the solar light reflected by the corona, as observed by JANSSEN in 1871, while, in the prismatic camera, the corresponding dark rings will be too diffuse to show themselves, for the reason that they come from so large an area.

Chromosphere and Prominences.

The advantages of the slitless spectroscope, in the case of the chromosphere and prominences, may be summarized as follows :—

(1.) Production of actual pictures. Unlike the slit spectroscope, it does not give the spectrum of one section only of the corona and prominences, but combines the functions of a telescope with those of a spectroscope, and gives actual views of the whole of the solar surroundings in each radiation strong enough to produce an image. Any chemical differences which there may be between different regions will be shown by the limitation of some of the spectral features to certain segments of the rings.

(2.) Prominences will be localised by the prismatic camera, so that their separation from the normal corona spectrum will be greatly facilitated. The superposition of such a spectrum upon those due to other sources, when a slit spectroscope is employed, prevents their recognition as local phenomena.

(3.) Elimination of the light from the prominences and corona scattered by the dust particles in our air. This light, though producing false lines in the spectrum of the corona, and even across the dark body of the moon itself when a slit spectroscope is employed, cannot by any possibility produce more than a general illumination of the field when viewed through a prismatic camera. Images of the corona can only be depicted by true coronal radiations, or by radiations reflected by the corona itself from the lower parts of the sun's atmosphere, if such reflected radiations be possible.

(4.) There is a great saving of light due to the absence of condensing lens, collimating lens, and slit, so that photographs may be obtained with shorter exposures, and, therefore, at a greater number of stages of the eclipse.

Comparison of Methods in the Case of Atmospheric Layers.

In a Paper communicated to the Society in 1882,* I pointed out the importance of considering the conditions under which we observe the phenomena of the sun's atmosphere. It was shown that whether the sun's atmosphere be composed of concentric layers of different composition, or of vapours, all of which rest on the photosphere and thin out at different heights, the phenomena observed with a slit spectroscope

* 'Roy. Soc. Proc.,' vol. 34, p. 292.

will, *in the main*, be the same in both cases, for the reason that we have to deal with the projection of a sphere and not with a section. The only criterion is that if the vapours rest on the photosphere, the lines will thicken towards the base, whereas, in the case of a separate higher layer they would not widen or brighten towards the base, but really be thickest at the top, if we do not take account of effects of temperature. Taking temperature into consideration, as the lines will be less bright as the distance from the sun is increased, and, therefore, the temperature is reduced, the lines produced by the higher layers will be of equal brightness throughout, and dimmer than the others. Accordingly the slit spectroscope can only give information as to the distribution of vapours in the sun's absorbing atmosphere by means of these very delicate observations of brightness, or widening of the bright lines observed.

Somewhat similar difficulties are met with in the case of the prismatic camera, when we attempt to distinguish between the two kinds of layers. First, consider the effects during totality. In the case of a vapour extending down to the photosphere, we should obtain spectrum rings decreasing in intensity as we pass outwards from the moon's limb (this is exemplified by the ring obtained in the case of 1474 K, to which reference will be made later, and the same appearance is seen in the case of the other coronal rings). The apparent internal diameters of such rings upon the photographs would be equal in every case, but their heights would depend upon the intensities of the radiations producing them. There should be no difficulty in detecting such rings unless they are of very nearly equal brightness, and very numerous, or unless they do not extend far enough to be visible beyond the moon.

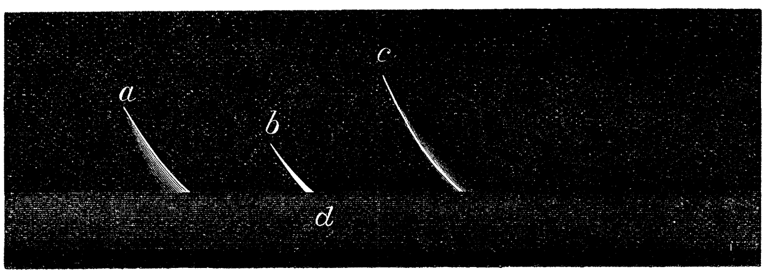
There is a very definite way in which the photographs taken with the prismatic camera may indicate the presence of layers of vapours concentric with the photosphere, but not reaching down to it. At a certain height above the photosphere, the chromosphere spectrum in a photograph of the chromosphere visible at any one instant beyond the edge of the moon, will show arcs with certain relative intensities. As the moon advances and gradually uncovers the base of the chromosphere, the same arcs will remain visible, but those produced by a layer which does not extend lower down will be reduced in intensity as compared with arcs produced by vapours which do reach lower down ; the latter will continue to get brighter, while the others remain of the same absolute intensity. As the lowest part of the chromosphere is shown in the photographs taken immediately after totality, or exactly at the end, it is only necessary to compare the relative intensities of the arcs in different photographs in order to investigate the general question as to the existence of layers. A large number of photographs taken in rapid succession with instantaneous exposures during the visibility of the chromosphere spectrum, either near the beginning or end of totality, would further enable us to determine the order of such layers in proceeding outwards from the photosphere.

Another way in which the prismatic camera may possibly help to determine the presence of layers is as follows. A layer concentric with, but separated from, the photosphere, will be shown in each of its radiations which is bright enough to be photographed, as a ring brightest at the outer edge, and dimming very rapidly towards the photosphere in consequence of its greater thickness in the line of sight near the tangent. If only the outer part were bright enough to be photographed, the ring would have a diameter greater than that of the moon. Layers considerably removed from the photosphere would be cool and dim, and their feeble images would tend to be lost in the general continuous spectrum. The diameters of the rings being different, true wave-lengths could not be assigned, and the superposition of a great number of them would give the appearance of a nearly continuous spectrum, in the part lying within the band equal in breadth to the moon's diameter. Outside this band, where the rings would be best visible, above and below the moon, on account of their different diameters, the direction of dispersion is such as to cause the greatest overlapping of images, and the consequent confusion would make the spectrum look nearly continuous, in the case of a considerable number of images. Hence there will be some difficulty in detecting the effects due to a very large number of concentric separate layers when the prismatic camera is employed during totality.

The conditions with regard to layers in the photographs taken out of totality with the prismatic camera, are somewhat as follows :—

If the vapours extend from the photosphere outwards, and are brightest at the base, the arcs due to them which appear at the cusps, provided they are bright

Fig. 11.



Possible appearances of bright arcs at cusp in photographs taken out of totality.

(*a*) Arc due to vapour extending from photosphere outwards, with gradually diminishing brightness.
(*b*) Arc due to a thin layer close to photosphere and equally bright throughout.
(*c*) Arc due to a shell of vapour, concentric with photosphere, but some distance from it.
(*d*) Continuous spectrum of photosphere.

enough to show themselves in the general illumination of the field will have a somewhat triangular appearance, with the maximum brightness nearest to the cusp as shown at *a*, in fig. 11.

The intensity of such an arc will gradually diminish in all directions from the cusp and its extension will depend upon intrinsic brightness. All the arcs will have the same internal radius.

A thin layer of vapour of equal brightness throughout, and resting on the photosphere, will give short arcs having the appearance shown at *b* in fig. 11; as we are observing a spherical shell, the appearance would not be different from that at *a*, but the edges of the arc might be expected to be more sharply marked.

In the case of a concentric shell some distance removed from the photosphere, its representative in the spectrum of the cusp will be a relatively long arc as at *c* in fig. 11, brightest near its outer edge, and suddenly dimming for the reason above stated.

Different layers of this kind will give arcs struck with different external radii. The arcs due to all but the brightest layers, however, will be lost in the general illumination of the field, and since the brightest vapours will be near to the photosphere, the differences of radii will not be very great, and as we are dealing with short arcs, these differences of radii will not help us to distinguish the outer shells in this way.

This suggests another consideration which may perhaps help us eventually, when higher dispersions are employed to distinguish concentric shells, if they exist. As the arcs due to them are brightest on the outside, they will appear to occupy places in the spectrum which do not correspond to their true wave-lengths. At the same time they will be longer, so that it is in the case of long arcs that we might expect to find departures from the true wave-lengths; if we found, for instance, three lines near iron lines with a constant difference from the true wave-lengths of the iron lines, we should be justified in regarding such lines as iron lines displaced in the manner indicated.

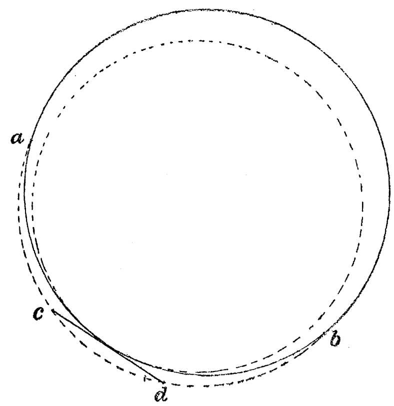
Comparison of the Methods in the case of Vapours close to the Photosphere.

The prismatic camera offers special advantages for the investigation of the vapours which lie nearest to the photosphere.

(1.) The spectrum of even a very shallow layer will be represented by arcs of considerable length in a photograph taken with the prismatic camera at the beginning or end of totality, the length of the arc corresponding to the whole of the layer uncovered by the moon at the time. With a slit spectroscope the lines will be relatively much shorter, even assuming that the slit can be placed exactly at a tangent to the moon's limb. This is shown in fig. 12, in which the continuous circle represents the moon, and the dotted one the disc of the sun. A layer of vapour resting on the photosphere is represented by the outer portion of a dotted circle. In the prismatic camera this layer would be represented by an arc of length *ab*, while, with the slit spectroscope, under the most favourable conditions, it will only be represented by a line of length *cd*.

No special adjustment of the instrument is necessary to enable such photographs to be obtained, whereas, with the slit spectroscope, the most accurate adjustment would be necessary.

Fig. 12.



Illustrating comparative lengths of arcs and lines photographed with prismatic camera and slit-spectroscope respectively, at beginning or end of totality.

(2.) The radiations of such vapours may be studied by means of photographs taken shortly before and after totality, for which no readjustment of the instrument is required. The bright arcs at the cusps are of greater length than the lines in similar photographs, which might be taken with slit spectroscopes.

Interpretation of Photographs taken during Totality.

The photographs taken during totality show the spectrum of the chromosphere and prominences as they appear at different heights above the photosphere.

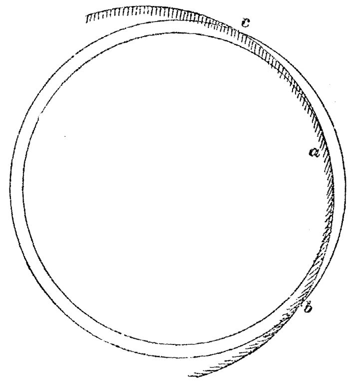
Thus, the metallic prominence shown in the upper right-hand quadrant in Photograph 7, Plate 11, appears also in Photographs 8, 9, 10, 11, the lower parts being gradually eclipsed, so that the last only shows the spectrum of the tip of the prominence.

In the case of the spectrum of the chromosphere, different parts of the arcs photographed correspond to the spectrum at different distances above the photosphere. Thus, at a position angle corresponding to the point of contact at the beginning or end of totality, the edge of the moon will reveal the chromosphere to a greater depth than at adjacent parts, as shown in fig. 13. If the inner circle represents the boundary of the photosphere, and the circle concentric with it represents the chromosphere, the edge of the moon, at the moment of contact, will be in some such position as *c a b*. At the point *a* we should at that moment get the spectrum of the base of the chromosphere, while at *b* and *c* we should only get the spectrum of the higher reaches.

In case the chromosphere consisted of concentric shells of vapour, the spectrum seen at the point *a* would be the integration of the spectra of all the shells of vapour, but at *c* and *b* only the outer shells would be effective in producing a spectrum.

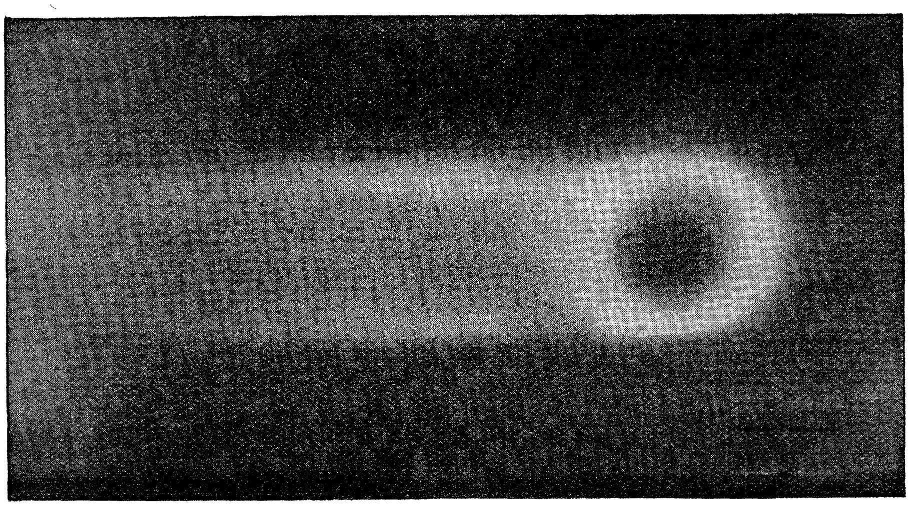
A point which it is important to bear in mind, when attempting to interpret the photographs taken during totality, is the production of rings by a purely continuous spectrum, when a slitless spectroscope is employed. Attention was drawn to this in the preliminary report,* and it was stated that the broad ill-defined ring, a little more refrangible than D_3 in some of the African photographs, as well as a less conspicuous one in the blue, and possibly even another in the violet, has its origin in the *continuous*

Fig. 13.



Illustrating different depths of chromosphere photographed with one exposure.

Fig. 14.



Appearance of continuous spectrum photographed on an isochromatic plate with a ring slit.

spectrum of the corona acting on a plate, which has one maximum of sensitiveness for the yellow rays and one or more maxima in the blue and violet. Experiments with ring slits, illuminated by a source of light giving a continuous spectrum, have confirmed this explanation. The photograph reproduced in fig. 14 was taken on an isochromatic plate with the 6-inch prismatic camera, temporarily provided with a $3\frac{1}{2}$-inch collimator in which the slit was replaced by a positive picture of the corona. A bull's-eye lamp

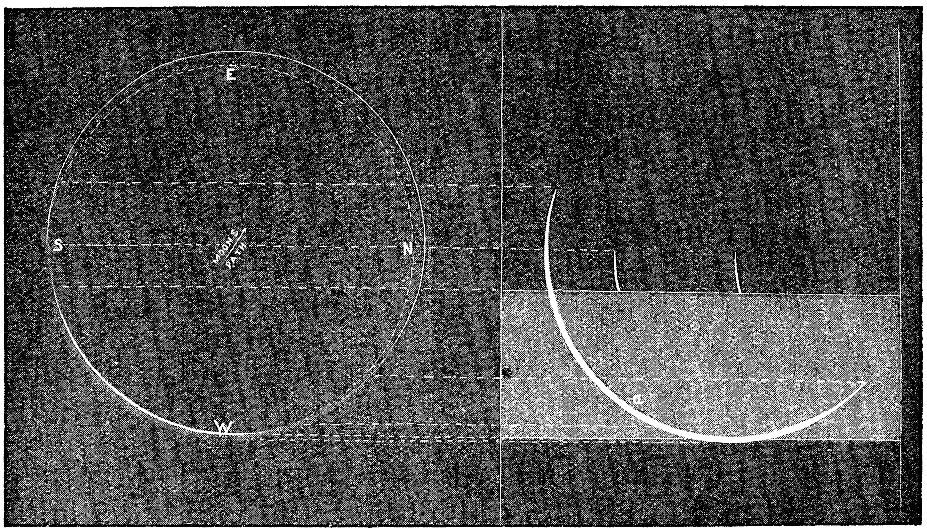
* 'Phil. Trans.,' 1894, vol. 185 A, p. 714.

was employed as a source of light, and it will be seen that although there was no suspicion of anything but continuous radiations, an appearance of rings was produced exactly resembling those to which reference has been made as taken during the eclipse.

Interpretation of the Photographs taken out of Totality.

The photographs taken out of totality greatly increase the chances of obtaining a record of the spectra of the vapours near the photosphere. It is evident that shallow strata can only be visible for a very short time after the beginning and before the end of totality, but they will be visible at the cusps out of totality, so long as the general illumination of the sky by the uneclipsed part of the photosphere is insufficient to mask them.

Fig. 15.



General explanation of photographs taken out of totality.

Fig. 15 will facilitate a general explanation of the photographs taken out of totality. The part of the diagram to the left represents the relative positions of the sun and moon at the African station about a minute after totality, there being a thin crescent of photosphere then visible in the south-west quadrant. Two imaginary layers of vapour are drawn round the sun. The direction of dispersion being north and south, the spectrum is drawn out in the direction indicated by the continuous spectrum in the part of the diagram on the right. It is evident that the radiations of the outer layer of vapour will be represented by long arcs in the spectrum of the cusp, while those proceeding from the lower vapour will be represented by shorter ones.

It may be remarked also that the lengths of the arcs at the cusps for any particular layer of vapour will depend upon the interval from totality at which the photograph is taken ; even a shallow layer will be represented by long spectrum arcs at the moments of 2nd and 3rd Contacts, but the lengths of these will be gradually diminished in consequence of the less oblique section of them which is made by the moon as totality is departed from.

If the vapours are evenly distributed in the layers the arcs at the cusp will be geometrically regular, but if they are disturbed, as we have reason to believe they may be, the forms of the arcs may not be regular, and they may be of unequal brightness in different parts.

Although irregularities of the vapours may be distributed all along the sun's limb, the conditions under which they are presented to us will vary with the distance from the cusp, just as in the case of uniform layers. A knot near the cusp would be fully revealed to us, and the prismatic camera would give us the spectrum of all its parts. A knot a little removed from the cusp, however, will have its base covered by the moon's edge, and only the spectrum of its higher parts will be seen. Taking the spectrum generally, it will have four origins :—(1) the spectrum of the vapours of the cusps, giving bright arcs; (2) the spectrum of the visible crescent of photosphere, consisting of a bright continuous spectrum crossed by dark arcs; (3) the spectrum of the vapours surrounding the uneclipsed part of the sun, giving bright arcs; (4) the spectrum of the corona, consisting of a relatively feeble continuous spectrum and a number of bright rings.

VIII. The Spectrum of the Corona.

List of Coronal Radiations.

Except in the case of 1474 K, the coronal rings are very feeble, and their wave-lengths can, perhaps, not be depended upon to within one-tenth metre. They were read off from the African negatives by direct comparison with the spectrum of Arcturus. Possibly, owing to the great intensity of the continuous spectrum, the Brazilian negatives show only 1474 K in the spectrum of the corona.

The accompanying table indicates the wave-length of the coronal radiations, and the number of the African photographs in which they have been detected. It is almost impossible to form any trustworthy estimate of the relative intensities of the rings, but it may be noted that the one at wave-length 3987 comes next to 1474 K in order of brightness

There are indications of other extremely faint rings, the positions of which cannot be determined with the necessary degree of accuracy to enable a useful statement to be made touching their wave-lengths.

Wave-length.	Numbers of the African photographs.								
	VII.	VIII.	IX.	XII.	XVI.	XVII.	XVIII.	XXI.	XXII.
3987	..	×	..	×	×	×	×	×	
4086	..	×	..	×	×	×			
4217	..	..	..	×	×				
4231	×	×	..	×	×	×	×		
4240	..	..	..	×					
4280	..	..	..	×	×				
4486	..	..	..	×	..	×	×		
5316·9	..	..	×	..	×	×	×	..	×

Comparison with Results Obtained by Slit Spectroscope.

Coronal rings, other than those due to 1474 K, or hydrogen, have not previously been recorded by the prismatic camera, though some of the lines corresponding to them appear to have been photographed with slit spectroscopes.

The coronal rings photographed in 1893 are compared in the following table with results obtained by the slit spectroscopes in the years 1882, 1883, 1886,* and 1893,† those lines only which are possibly common being included.

Prismatic Camera, 1893. λ R.	Slit Spectroscopes, 1893. λ A°.	Slit Spectroscopes, 1886. λ A°.	Slit Spectroscopes, 1883. λ A°.	Slit Spectroscopes, 1882. λ A°.
3987	3986·4	3985·0 (1)‡	3986 ?	
4086	..	4084·2 (4) 4089·3 (4)	} 4085	4085
4217	..	4216·5 (3)		
4231	..	4232·8 (5)		
4240	..	4241 (4)	..	4241
4280	4279·7	4280·6 (4)	4279	
4486	..	4485·6 (3)		

We see then that all the coronal radiations above referred to probably correspond with lines photographed by Dr. SCHUSTER in 1886. The intensities, however, are not the same.

The number of coronal rings recorded with the prismatic camera is very much smaller than the number of lines attributed to the corona photographed with the slit spectroscopes in this and previous eclipses. This is, no doubt, partly due to the rings

* 'Phil. Trans.,' 1889, A, p. 335.

† 'Roy. Soc. Proc.,' vol. 56, p. 20.

‡ Intensity on a scale where 6 = brightest line.

being submerged in continuous spectrum, which is relatively more intense in the case of the prismatic camera. Further, as already pointed out, it is not yet established that many of the lines recorded in the corona by the slit spectroscopes are not due to glare.

By a comparison of the results obtained with slit spectroscopes and prismatic cameras, it would seem to be possible to determine which of the lines recorded by the former instruments really belong to the coronal spectrum. The most intense light will give the strongest glare, and therefore the brightest lines of the chromosphere and prominences will become superposed on those due to the corona. As the results obtained with the prismatic cameras are so very definite with regard to the spectrum of the prominences, it seems only necessary to subtract the common lines of the spectra recorded by the two instruments from the total number recorded by the slit spectroscopes in order to determine those which certainly belong to the corona.

An attempt has been made to investigate the coronal spectrum in this way by reference to the slit spectra of 1886 and 1893, but no satisfactory results can be obtained in this way until slit spectra taken with greater dispersion become available.

In the case of the rings, the evidence that they truly belong to the corona is absolutely conclusive.

Comparison with Fraunhofer Spectrum.

In the absence of more exact knowledge of the wave-lengths of the radiations producing the rings, it is not yet possible to determine if they are represented by dark lines in the Fraunhofer spectrum, but it can already be stated that, if present at all, they are among the feeble lines.

Comparison with Prominence Spectrum.

A point of some importance is the apparent absence of the 1474 K ring from the spectra of the chromosphere and prominences. A similar absence of 1474 K from the prominence spectrum was noted by RESPIGHI in the eclipse of 1871. I am not aware of any observation in which the *form* of a prominence has been observed in 1474 light. All these facts seem to indicate that when the 1474 is observed at the sun's limb without an eclipse, the spectrum of the corona itself is under examination, under the same conditions as those recorded in the eclipse photographs.

Of the other coronal rings photographed in 1893, those at wave lengths 4217 and 4280 are approximately coincident with feeble prominence radiations, but since the other coronal rings are not represented in the prominences, the coincidences may be regarded as accidental.

Although H and K are by far the most intense of the radiations of the prominences, on no occasion have they been photographed as rings in the spectrum of the *corona* with the prismatic cameras. They have, however, been occasionally recorded as corona lines with slit spectroscopes, but it does not seem improbable that in most cases they were produced by prominence light scattered by our atmosphere, as before explained—light of which the prismatic camera takes no account.

Perhaps the most decided evidence in favour of the existence of H and K in the corona spectrum is that depending upon the photographs taken with slit spectroscopes in 1886; Dr. SCHUSTER states that "the lines end sharply with the corona, and we must conclude, therefore, that in spite of the unfavourable atmospheric conditions, there was but little light scattered by our own atmosphere in the neighbourhood of the sun."

But in spite of this observation, Dr. SCHUSTER has concluded that H and K "do not form part of the normal spectrum of the corona";* and I may add that the prismatic camera strengthens this conclusion.

The "Continuous" Spectrum.

The photographs taken with the prismatic cameras in 1893 show a pretty strong "continuous" spectrum, but it has already been explained that this appearance may have been produced by a very complicated spectrum, such as that which I observed in the corona in 1882. Concerning my observations, I wrote :—†

"Instead of the gradual smooth toning seen, say, in the spectrum of the limelight, there were maxima and minima, producing an appearance of ribbed structure, the lines of hydrogen and 1474 being, of course, over all. This observation, however, requires confirmation, for the look I had at the corona spectrum was instantaneous only."

IX. THE VARIABILITY OF THE SPECTRUM OF THE CORONA.

General Comparison of the 1893 Results with Earlier Observations.

A change in the spectrum of the corona was placed beyond all doubt in my own mind by my observations in 1871 and 1878. With reference to this I wrote as follows in 1878 :—‡

"The utter disappearance of the large bright red corona of former years in favour of a smaller and white one in this year of minimum struck everybody. Indeed, it is remarkable that after all our past study of eclipses this last one should have exhibited phenomena the least anticipated. It isolates the matter that gives us the continuous spectrum from the other known gaseous constituents. The present eclipse has accomplished, if nothing else, the excellent result of intensifying our knowledge concerning the running down of the solar energy. On the former

* 'Phil. Trans.,' vol. 180, A, p. 341.

† 'Roy. Soc. Proc.,' vol. 34, p. 299.

‡ 'Nature,' vol. 18, p. 460.

occasion in 1871, the 1474 ring was very bright, but in 1878 I did not see it at all.'' As the sun-spot period is one of about eleven years, it was to be expected that the conditions of 1871 would be repeated in 1882 and 1893, and during both these eclipses the 1474 ring was photographed with the prismatic cameras. The photographic plates employed in 1875 and 1886 were not sensitive to the green, and, since no eye observations were made, we have no evidence as to the visibility of the 1474 ring in those years.

Although there can be no doubt as to a more or less regular change of intensity in the case of 1474 K, the evidence with regard to other radiations is less conclusive.

Confining our attention in the first instance to the results obtained with slitless spectroscopes, we have the following data :—

Date.	Observers.	Method.	Spectrum.
1871	RESPIGHI	Visual	C, 1474 K, F.
,,	LOCKYER	,,	,, ,, F.G.
1875	SCHUSTER	Photographic	G.
1878	LOCKYER	Visual and Photographic	Continuous
,,	RANYARD	Visual	,,
,,	DRAPER	Photographic	,,
1882	SCHUSTER	,,	D_3, 1474 K
,,	LOCKYER	Visual	C, 1474 K
1883	LAWRENCE and WOODS	,,	1474 K (middle of totality)
,,	,, ,,	Photographic	Continuous
1886	DARWIN	,,	,, (plate not sensitive to 1474 K)
1893	FOWLER	,,	1474 K and 7 others
,,	SHACKLETON	,,	1474 K
,,	,,	Visual	,,

Variation of Hydrogen.

Hydrogen rings have only been recorded in the spectrum of the corona on three occasions—1871, 1875, and 1882; it is probable that the rings corresponding to hydrogen seen in 1883 were produced by the chromosphere and prominences, since they were not seen in the middle of totality. If the appearance of the hydrogen rings in the corona have the same connection with the sun-spot period as the 1474 K line, their presence in 1893 might have been expected. As they were not photographed in this eclipse, the appearance of hydrogen rings might be regarded as subject to no law in relation to the sun-spot period, but, before coming to a decision on this point, it is worth while to consider very carefully the differences in the instruments employed in the various eclipses. To get at these facts Mr. FOWLER has made a number of experiments to determine to what extent false rings may be produced in the visible and photographic spectrum when a slitless spectroscope is employed, similar to those produced photographically in the manner already explained when certain plates are employed. A positive photograph of the corona of 1893, some 6′ high, illuminated by a large gas flame or electric lamp, forms an artificial eclipse, which has been viewed with instruments of different dispersions, at a distance such that the diameter subtended an angle of about 32′. With a very small dispersion, similar to that employed by RESPIGHI in 1871 in relation to the apparent size of the ring, one sees circular spectra, approximating very closely to those described and figured by RESPIGHI;* the effect is best seen when the green ring is intensified by introducing a salt of thallium between the poles of the electric arc, when the latter is employed as a source of light. A green ring, sharply defined on its inner edge, then becomes visible, a red ring is very distinct but ill-defined, and a blue ring is still less distinct. With increased dispersion, similar to that I employed in 1871, all traces of the blue and red rings disappear, and the green one is only visible so long as there is a special green radiation.

These experiments suggest that the very broad blue and red rings recorded by RESPIGHI in 1871 are possibly not conclusive evidence that the H_α and H_β radiations of hydrogen were very strong in the spectrum of the corona, as rings strikingly resembling them can be produced by a continuous spectrum alone when viewed with similar instrumental conditions. At the same time no such doubt is thrown upon my own observations of narrow rings which were made with the dispersion of five prisms, as false rings of red and blue light are not seen under these conditions. The red and blue hydrogen rings, as I saw them in 1871, were about 2′ high, and bright compared with 1474 K; my observations were made earlier in the eclipse than those of RESPIGHI, to which reference is made above, but the fact that I did not see D_3 seems conclusive evidence that I was not observing rings due to the chromosphere and prominences. Hydrogen was, therefore, certainly present in the corona of 1871 to a height of about 2′, but the observations suggesting its spectroscopic visibility at a greater height are not conclusive.

With regard to the photograph of 1875, in which H_γ was definitely ascribed by Dr. SCHUSTER and myself to the corona, the absence of corona rings corresponding to H and K, which are the strongest lines of the chromosphere and prominences, appears to support the idea that the H_γ ring was not due to chromosphere or prominences. A photograph of the artificial corona, illuminated by an incandescent lamp, under instrumental conditions closely approximating to those employed in 1875, shows only a *hazy ring* near H_γ, corresponding to the region of maximum sensitiveness of the plate; in this way a sharply defined ring similar to that on the photograph cannot be obtained.

It is probable, therefore, that in 1875, as well as in 1871, hydrogen was present in the inner corona.

My observations in 1882† also gave indications of hydrogen.

* 'Atti della Reale Accad. dei Lincei,' March 3, 1872, p. 17.

† 'Nature,' vol. 26, p. 101.

No hydrogen rings were seen during the eclipse of 1878, and as the slitless spectroscopes employed by DRAPER, RANYARD, and myself were of considerable dispersive power, no appearances of rings due to continuous spectrum could have been produced. The presence of hydrogen rings about the time of sun-spot maxima in the eclipses of 1871 and 1882, and their absence near the time of minimum in 1878, suggests a relation to the sun-spot period, similar to that which has been established in the case of 1474 K, but as the rings are not shown in the photographs taken at the maximum in 1893, a final verdict cannot yet be given as to whether hydrogen varies with the sun-spot period.

Reference to Helium.

As shown in the table, the D_3 ring was stated to have been photographed in Egypt in 1882, but not on any other occasion.* From the description of the ring given in the report of this eclipse,† it seems very probable that it is similar to the broad yellow ring photographed on the isochromatic plates in 1893, which, as already shown, is due to the action of continuous spectrum acting on plates with several maxima of intensity in different parts of the spectrum. It is described as being more uniform all round the sun than the 1474 ring, and this is the case also in the 1893 photographs, on which the ring in question is a little more refrangible than D_3; but in the smaller scale photograph of 1882 this difference of position may not have been evident, or the 1882 plate may have had one of its maxima of photographic action still nearer to D_3. In the absence of a copy of the photograph it is difficult to determine how far this explanation holds good, but, if it should be established, this, in combination with all the other eclipse records, would prove that D_3 does not form part of the coronal spectrum.

Reference to Unknown Radiations.

As to the variation in intensities of other radiations of the corona, no evidence is furnished by the prismatic camera results alone. The table of coronal rings already given (p. 593) suggests a similarity of the 1886 spectrum with that of 1893, but the conditions under which the two series of observations were made were so different, that it would be unwise to draw any conclusions as to the variation of the feebler radiations.

At present, then, there is no continuous and distinct instrumental evidence of a periodic change of specific parts of the spectrum, other than the varying brightness of 1474 K.

* As stated in the preliminary report on the eclipse of 1893 ('Phil. Trans.,' vol. 185, 1894, A, p. 716), a yellow ring was seen by Mr. SHACKLETON in Brazil; the subsequent discussion has shown that this must be ascribed without hesitation to chromosphere and prominences, and not to the corona.

† 'Phil. Trans.,' vol. 175, 1884, Part I., p. 264.

Variability of the Continuous Spectrum.

No data have been recorded in regard to the varying intensity of the so-called continuous spectrum of the corona, but, from my spectroscopic observations of 1871, 1878, and 1882, there is no question whatever in my mind that there is a considerable variation in brightness in this continuous spectrum at the maximum and minimum sun-spot periods. The absence of definite statements seems to suggest the desirability of having this question studied by means of the visibility of stars, and, if possible, numerical data should be obtained at each eclipse.

During the eclipse of 1886 the sun itself was clouded over, as seen from the station occupied by myself in the West Indies; but in other parts of the sky a great number of stars was visible—a much greater number than is visible at full moon. At the African station in 1893, the corona was so bright that only the planets Jupiter and Venus were seen by Mr. FOWLER.

There is, however, direct evidence of change of the total light of the corona plus the prominences and chromosphere from one eclipse to the other; and it is probable that the brightness of the so-called continuous spectrum varies in the same way.

Photometric measurements made in the eclipse of 1870 showed that the total light of the corona was represented by 0·42 of a standard candle at a distance of a foot.* Similar observations made in 1878 led Professor HARKNESS to conclude that the total light of the corona was 0·072 of the same unit.†

In 1886 the greatest value registered for the total light was 0·02 of the same unit, but in connection with this low estimate it is pointed out that the conditions of observation were not so favourable as in 1878.‡ Photometric observations were made in 1893, but the results have not yet been published.

Thus, the greatest brightness of the total light was recorded at a sun-spot maximum, while the light was very much less near the times of minima.

So far as they go, these facts agree with the view that the true corona is brightest near a sun-spot maximum.

The more solar physics is studied, the more an enormous change from maximum to minimum in all the phenomena is revealed. Besides this variability of the corona there is, in addition to the well-known eleven-yearly variation in the number of spots, faculæ, and prominences, a variation in the spectra of sun spots so marked, as I have shown in other communications, that there are few, if any, widened lines common to the maximum and minimum.

* 'U. S. Coast Survey Reports,' 1870, p. 172.

† 'Washington Observations,' 1876, App. III.

‡ 'Phil. Trans.,' vol. 180, A, p. 381.

X. Wave-lengths and Intensities of the Prominence and Chromosphere Lines.

Determination of Wave-lengths.

The wave-lengths throughout are expressed on Rowland's scale. In the region less refrangible than K, they have been determined from the African photographs, by comparison with the spectrum of Arcturus and other stars photographed with the same instrument, the wave-lengths of the lines in which were determined by reference to Rowland's photographic map. The spectrum of Arcturus is almost identical with that of the sun, so that the comparison lines were sufficiently numerous for the purpose. Stars like Bellatrix were employed as an additional check in the case of bright lines not coincident with prominent Fraunhofer lines.

Micrometric measurements of the lines were also made and reduced to wave-lengths in the usual way, by means of a curve; these furnished a check on the general accuracy.

In the case of the Brazilian negatives the wave-lengths were determined by means of micrometric measures and a curve, and checked by direct comparisons with a solar spectrum, photographed with the same spectroscope while it was temporarily provided with a slit and collimator.

For the reduction of the ultra-violet, in both series of photographs the wave-lengths of the hydrogen lines have been assumed as far as H_ϕ from those given by Hale,* with the exception of H_υ, which falls sufficiently near the calculated wave-length to be accepted as a hydrogen line.

With these as datum lines, wave-length curves were constructed, and the wave-lengths of the other lines found by interpolation.

The wave-lengths of the radiations more refrangible than H_ζ were determined from extrapolation curves, so that the degree of accuracy is necessarily less than in the case of the remaining lines.

The first column of Table I. summarizes the wave-lengths of the lines which have been measured in all the negatives in both series, whether occurring in the spectrum of the chromosphere or prominences. Although the total number of lines photographed in Brazil is smaller than that photographed in Africa, a few of them only appear in the Brazilian photographs; these are at wave-lengths 3674·2, 3679·5, 3748·5, 4934·2, 5018·6, and 5047·8.

* 'Astronomy and Astrophysics,' 1892, pp. 50, 602, 618.

Determination of Intensities.

The scale of intensities which has been adopted is such that 10 represents the brightest lines and 1 the faintest. This will facilitate comparisons with YOUNG's well-known list of chromospheric lines, in which 100 represents the maximum frequency and brightness. The intensities have been estimated by taking the strongest line in each negative as 10, irrespective of length of exposure.

Table I. gives the intensities of the various lines as they appear in different photographs of prominences Nos. 3 and 19, and in the spectrum of the cusp a few seconds after totality. The intensities of the lines in different photographs of the spectrum of another prominence, No. 13, are shown in Table II., and those at the outside of the chromosphere are contrasted with the intensities of the same lines at the base in Table III.

XI. LOCI OF ABSORPTION IN THE SOLAR ATMOSPHERE.

The Spectra of Prominences and Chromosphere at Different Heights.

If we consider a prominence on that part of the sun's limb where the second contact takes place, the first photograph taken during totality will show the spectrum of the whole prominence, and succeeding photographs will give the spectrum of the same prominence with the lower parts gradually cut off by the moon's edge. In the case of a prominence at the opposite limb, similar sections will be represented in successive photographs, and the last photograph taken during totality will show the spectrum of the greatest part of the prominence.

Prominences Nos. 3 and 19 (see fig. 10) have been investigated in this way, and particulars of their spectra at various heights are recorded in Table I. The first of them is shown in the African Photographs Nos. 7 to 13 inclusive, and the latter in Photographs 19 to 21 inclusive. The height above the photosphere, reckoned in seconds of arc, and in miles, at which each spectrum is given, is indicated beneath the numbers of the photograph in which the prominences appear. The relative intensities of the lines at different heights are shown by the figures ranged in horizontal lines with the wave-lengths. Some of the lines remain of the same relative intensity throughout all parts of the same prominence; others again dim rapidly in passing towards the upper parts. The two prominences in question are also seen to behave differently in respect to some of the lines; thus the line at λ 3856·5 disappears before a height of 2,000 miles is reached in prominence No. 3, but remains visible at a height of over 4,000 miles in prominence No. 19. Lines also occur in one prominence which do not appear in the other, *e.g.*, λ 4313·2. Other differences are also revealed by the table, but it may be remarked that too much stress should not be laid on the presence or absence of the very faintest lines in some of the photographs, as variations may be partially attributed to differences in the quality of the photographs.

The spectrum of a large prominence, No. 13 (fig. 9) at various heights from the photosphere, is shown in Table II. This prominence appears in all the African photographs taken during totality, and in some of those taken out of totality. In order that the changes of intensity of the various lines may be separated from the effects due to varying exposures, the individual observations are arranged in groups according to the exposure of the photographs. The total number of lines is much smaller than in the case of the two metallic prominences, but somewhat similar variations of intensity are noticeable.

The spectrum of the chromosphere at different heights can also be partially investigated in the eclipse photographs. A considerable arc of chromosphere was photographed in the African Negative, No. 21 (Plate 11). The photograph was taken about ten seconds before the end of totality, so that the lower reaches of the solar atmosphere within 1,660 miles of the photosphere were hidden. The bright arcs accordingly represent the spectrum of the chromosphere above that height. None of the photographs give us any information as to the spectrum lower down until we come to the part very near to the base which, as already explained, is shown at the cusp in Photograph 22 (Plate 13). The complete spectrum of the base of the chromosphere is given in Table I., and in Table III. the lines common to the outer part of the chromosphere and to the base are brought together for comparison.

Most of the lines become relatively brighter as the base of the chromosphere is approached, but some become dimmer. Further reference to these changes will be made later.

The changes in the spectrum of a prominence in passing from the top towards the base are illustrated in Plate 14. Spectra *a*, *b*, and *c* represent the spectrum of Prominence No. 3 as it appears in the African Photographs Nos. 11, 9, and 7 respectively, the first giving the spectrum of the upper part only, while the last shows the spectrum nearer the base. Accepting the time of commencement of totality in Africa as 2 hrs. 23 mins. 48 secs. by the deck watch, it is easily calculated that Spectrum 1 represents a part of the prominence 22″–26″ (9,950 to 11,600 miles) above the photosphere ; Spectrum 2, 6″·7–8″·5 (3,000 to 3,800 miles) ; and Spectrum 3, 3″·7 (1,660 miles) above the photosphere. Strip *d* is the spectrum of the base of the chromosphere as represented by the cusp in the African Photograph No. 22.

These enlarged spectra have been obtained by covering copies of the original negatives with tinfoil, leaving only narrow strips showing the prominence spectra, and giving them the necessary width by moving the photograph in a direction at right angles to the length of the spectrum, as described in a former paper.*

The want of exact coincidence of lines common to different horizons is due to the difficulty of obtaining enlargements on exactly the same scale. The difference in thickness of the same line in different photographs of a prominence is due to the varying sizes of the corresponding images of the prominence formed by the prismatic camera at different stages of the eclipse.

* 'Phil. Trans.,' 1893, vol. 184, A, p. 684.

The "Reversing Layer."

As a result of solar spectroscopic observations, combined with laboratory work, Dr. FRANKLAND and myself came to the conclusion, in 1869, that at least in one particular KIRCHHOFF's theory of the solar constitution required modification. In that year we wrote as follows * :—" May not these facts indicate that the absorption to which the reversal of the spectrum and the Fraunhofer lines are due takes place in the photosphere itself, or extremely near to it, instead of in an extensive outer absorbing atmosphere ?"

In an early observation of a prominence on April 17, 1870, I found hundreds of the Fraunhofer lines bright at the base, and remarked that "a more convincing proof of the theory of the solar constitution put forward by Dr. FRANKLAND and myself could scarcely have been furnished." †

During the eclipse of 1870, at the moment of disappearance of the sun, a similar reversal of lines was noticed ; we had, to quote Professor YOUNG, " a sudden reversal into brightness and colour of the countless dark lines of the spectrum at the commencement of totality." On these observations was based the view that there was a region some 2″ high above the photosphere, which reversed for us *all* the lines visible in the solar spectrum; and on this ground the name "reversing layer" was given to it.

Continued observations, however, led me, in 1873, to abandon the view that the absorption phenomena of the solar spectrum are produced by any such thin stratum, and convinced me that the absorption took place at various levels above the photosphere. I need not give the evidence here ; it is set forth in my 'Chemistry of the Sun.' ‡ On the latter hypothesis, the different vapours exist normally at different distances above the photosphere according to their powers of resisting the dissociating effects of heat. §

My observations during the eclipse of 1882, in the seven minutes preceding totality, to my mind set the matter at rest. " We begin with one short and brilliant line constantly seen in prominences, never seen in spots. Next, another line appears, also short and brilliant, constantly seen in prominences ; and now, for the first time, a *longer* and thinner line appears, occasionally noted as widened in spots ; while, last of all, we get very long, very delicate relatively, two lines constantly seen widened in spots, and another line not seen in the spark and never yet recorded as widened in spots." ||

Similar observations in the same part of the spectrum were made by Professor

* 'Roy. Soc. Proc.,' vol. 17, p. 88.
† 'Roy. Soc. Proc.,' vol. 18, p. 358.
‡ Chapter xxii., pp. 303–309.
§ 'Roy. Soc. Proc.,' vol. 34, p. 292.
|| 'Roy. Soc. Proc.,' vol. 34, p. 297.

TURNER in 1886.* His observations were made under less favourable conditions than those in Egypt, and in the absence of statements as to the relative lengths of the lines observed, it is impossible to utilise them.

This is one of the most important points in solar physics, but there is not yet a consensus of opinion upon it. Professor YOUNG and others apparently still hold to the view first announced by Dr. FRANKLAND and myself in the infancy of the observations, that the Fraunhofer absorption takes place in a thin stratum, lying close to the photosphere.

It is, therefore, of the highest importance to determine what light is thrown on the subject by the photographs of 1893.

A study of the distribution of the lines recorded in Tables I., II., and III., throughout the different parts of the chromosphere and prominences as revealed at different phases, proves that the spectrum gradually becomes more complex as the photosphere is approached.

A partial photographic record of the reversal of the lines at the beginning of totality was secured in Brazil (Photograph No. 2), and of the reversal near the end in Africa (Photograph No. 22). Owing to over exposure, the Brazilian photograph (Plate 12) is very dense, and the lines are only distinctly seen in the regions F to *b*, and that more refrangible than K. The African photograph, taken just after totality (No. 22, Plate 13), shows the ends of the long bright arcs visible at the end of totality, and we seem to be justified in taking these arcs as representing the reversals seen in former eclipses. The number of these bright arcs, as well as the Brazilian photograph No. 2, indicates a spectrum of considerable complexity near the base of the sun's atmosphere.

The complexity of the spectrum of the sun's atmosphere in the neighbourhood of the photosphere is indicated in another way. In the African photographs, taken after totality, except at the southern cusp, the spectrum, as already pointed out, is due to the following four sources:—(1) The spectrum of the vapours of the cusps, giving bright arcs; (2) the spectrum of the visible crescent of photosphere, consisting of a bright continuous spectrum crossed by dark arcs; (3) the spectrum of the vapours surrounding the uneclipsed part of the sun, giving bright arcs; (4) the spectrum of the corona, consisting of a relatively feeble continuous spectrum and a number of bright rings.

The results vary with the relative intensities of the different sources, the chief variable being the breadth of the photosphere, depending upon the interval from totality.

When the crescent is very thin, as in the African Photograph, No. 22, the bright chromospheric arcs are relatively strong and are seen crossing the continuous spectrum of the photosphere, while the dark arcs due to the photosphere are absent. RESPIGHI observed a similar absence of the Fraunhofer spectrum just after totality in

* 'Phil. Trans.,' 1889, vol. 180, A, p. 391.

1871, but he does not seem to have attached any special importance to it. It may be that the feeble Fraunhofer spectrum is under these conditions lost in the bright continuous spectrum of the lower corona; or, since the bright arcs due to hydrogen and calcium are strong enough to be seen superposed on the continuous spectrum of the chromosphere, it is conceivable that the Fraunhofer lines are masked by a complicated radiation spectrum from the base of the chromosphere such as would be furnished by the supposed reversing layer.

To produce the latter result, however, it is not necessary that every dark arc should have its counterpart among the bright ones due to the chromosphere, for the reason that during the exposure of this photograph the chromosphere was broader than the photosphere. The breadth of the chromosphere was about 8″, while that of the photosphere in its widest part varied from 1″ to 3″; thus some of the chromospheric arcs would be broad enough to mask several of the close dark ones in their vicinities, and the absence of the Fraunhofer lines in this photograph therefore does not necessarily favour the existence of a "reversing layer."

A consideration of the photographs disposes of any suggestion which may be made as to the possible production of an apparently continuous spectrum by the crowding together of a great number of short bright arcs, in the spectrum of the cusp, proceeding from the very lowest part of the chromosphere. The actual appearance of the African Photograph No. 22, Plate 13, did at first suggest that such was the case, the continuous spectrum of the photosphere having an excess of brightness immediately at the cusp where it joins the bright arcs. In the succeeding photographs, however, there is no such brighter band of continuous spectrum at the cusp, and the band which appears in Photograph 22 is seen to retain the same position as referred to the images of the prominences.

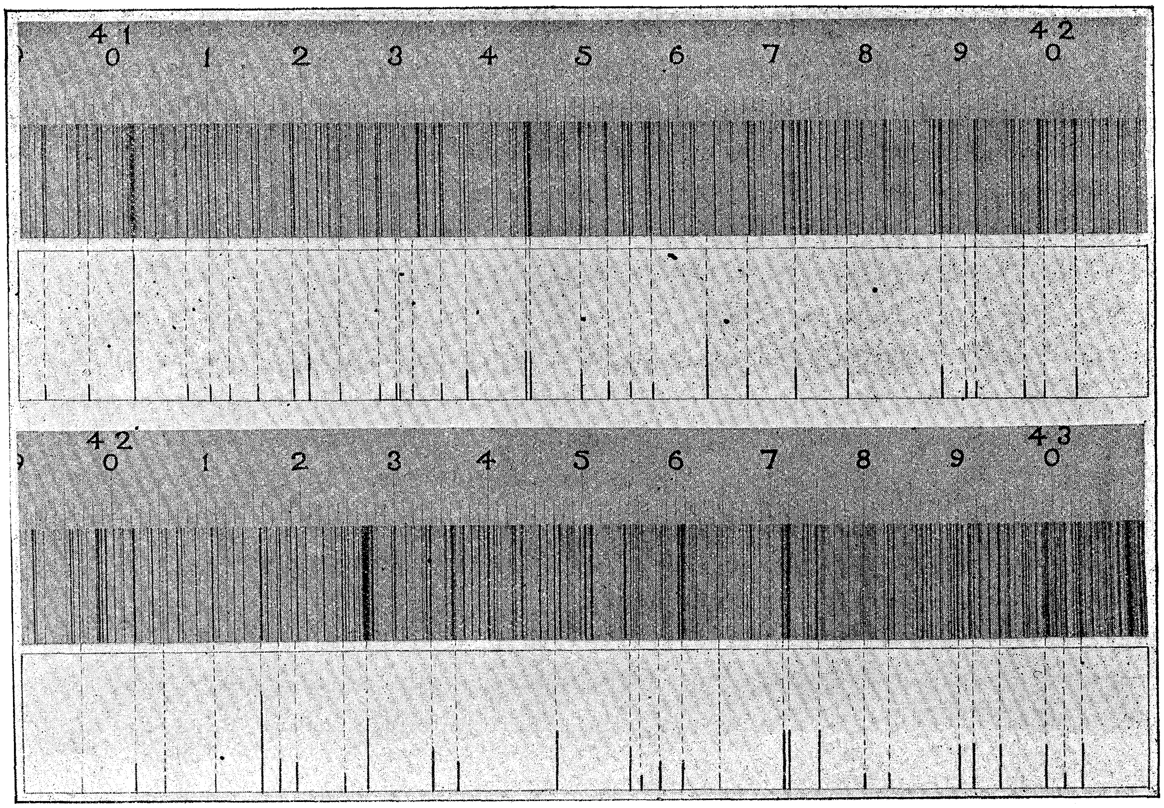
It seems probable, therefore, that the bright continuous band at the cusp, in No. 22, is due to an indentation of the moon's limb at the point where it was produced and that its coincidence with the cusp in the photograph is accidental.

In fig. 16, the bright arcs recorded in the African Photograph No. 22 are drawn in juxtaposition with a photographic map of a portion of the solar spectrum with lengths proportional to their intensities.

It becomes evident at once that the radiation spectrum is most distinctly *not* identical with the Fraunhofer spectrum; the most important point is that some of the strongest bright lines do not appear among the dark ones in the solar spectrum, while some of the strongest dark lines are not seen bright in the spectrum of the stratum of vapours in immediate contact with the photosphere. The region covered by the diagram lies between wave-lengths 4100 and 4300, but similar results follow when other regions are included in the inquiry.

These positive conclusions are not weakened by the consideration that the resolving power of the prismatic cameras employed is not sufficiently great to show all the lines of the Fraunhofer spectrum, which is used as a term of comparison; in fact, working under exactly the same conditions as during the eclipse, the instrument employed in Africa only shows 104 lines in the spectra of stars resembling the sun, in the region *h* to H, in place of 940 given in ROWLAND'S tables of lines in the solar spectrum. We, therefore, get a better term of comparison if we employ the spectrum of some star, such as Arcturus, which closely resembles the sun. Such a comparison is shown in Plate 14 ; out of 104 lines which the instrument is capable of depicting in the region *h* to H, only 40 are shown in the spectrum of the base of the sun's atmosphere. This comparison amply confirms the conclusion that the lines reversed

Fig. 16.



Comparison of the spectrum of the base of the chromosphere with Fraunhofer lines.

at the beginning or end of totality, though fairly numerous, do not correspond in intensity, though some of them correspond in position with the dark lines of the solar spectrum, and consequently that the so-called "reversing layer" close to the photosphere is incompetent to produce, by its absorption, the Fraunhofer lines. Further, while the chromosphere fails to show most of the lines which are present in the Fraunhofer spectrum, it shows many bright lines which are not represented among the dark ones. This again indicates that the chromosphere is not the origin of the Fraunhofer spectrum.

This striking result is absolutely in harmony with all the spectroscopic observations of the sun with which I am acquainted. The Italian observations of the quiet solar atmosphere and the Kensington observations of sun-spots may be especially mentioned. Not only is there no correspondence in intensity, but the variation in the sun-spot spectrum from maximum to minimum is enormous, while the Fraunhofer lines remain constant.

The Brightness of the Arcs at Different Levels.

The existence of a thin stratum competent to produce the Fraunhofer spectrum being thus disproved by the eclipse photographs, we have next to see if there are any indications as to the localization of the absorbing vapours which are not represented in the base of the chromosphere.

The most direct evidence which the eclipse photographs give as to the separation of the solar atmospheric vapours into layers is that afforded by the increased relative brightness of some of the lines in passing to higher levels.

As we have to deal with the projection of a sphere and not with a section of the sun's atmosphere, the spectrum arcs would brighten in passing outwards from the photosphere in consequence of the increased thickness of vapour presented to us, even if the radiation per unit volume remained constant. The spectroscopic differences recorded in Tables I., II., and III., however, show numerous inversions even in the behaviour of the same line in different prominences, so that the increased brightness observed cannot always be due to this cause alone.

Some of the lines are brightest at the base of the chromosphere, while others are brighter at greater elevations. As already explained (p. 586), lines which are brightest above the photosphere must be produced by vapours existing in layers concentric with, but detached from the photosphere. Those lines which become dimmer in passing outwards must owe their origin to vapours resting on the photosphere.

In contrasting the spectrum of the prominences with the spectrum of the cusp, it should be borne in mind that the cusp in the African Photograph No. 22 does not represent the base of the chromosphere immediately beneath either of the metallic prominences considered in Table I. Still the cusp is not far from prominence No. 19, and it is fair to consider the base of the chromosphere homogeneous. If so, the prominences cannot be fed from the base of the chromosphere, since they contain different vapours.

The preliminary discussion of individual substances has further abundantly shown that although some of the lines belonging to any particular metal may appear as dark lines in the solar spectrum on account of absorption by the chromosphere, other lines of the same substance are only represented among the dark lines because of absorption taking place elsewhere. This again is an indication of the stratification of the sun's absorbing atmosphere, which, if it exists, must furnish a very strong argument in favour of the dissociation of metallic vapours at solar temperatures. In fact, the eclipse phenomena have been found to be as bizarre, in relation to the non-dissociation hypothesis, as those which I have already discussed in relation to observation of sun spots and of the chromosphere and prominences without an eclipse.

The view I expressed in 1879,* and to which I adhere, is therefore strengthened by the eclipse work. I then wrote: "The discrepancy which I pointed out, six years ago, between the solar and terrestrial spectra of calcium is not an exceptional, but truly a typical, case. Variations of the same kind stare us in the face when the minute anatomy of the spectrum of almost every one of the so-called elements is studied. If, therefore, the arguments for the existence of our terrestrial elements in extra-terrestrial bodies, including the sun, is to depend upon the perfect matching of the wave-lengths and intensities of the metallic and Fraunhofer lines, then we are driven to the conclusion that the elements with which we are acquainted here do not exist in the sun."

XII. General Conclusions.

(1.) With the prismatic camera photographs may be obtained with short exposures, so that the phenomena can be recorded at short intervals during the eclipse.

(2.) The most intense images of the prominences are produced by the H and K radiations of calcium. Those depicted by the rays of hydrogen and helium are less intense and do not reach to so great a height.

(3.) The forms of the prominences photographed in monochromatic light (H and K) during the eclipse of 1893, do not differ sensibly from those photographed at the same time with the coronagraph.

(4.) The undoubted spectrum of the corona, in 1893, consisted of seven rings besides that due to 1474 K.

The evidence that these belong to the corona is absolutely conclusive. It is probable that they are only represented by feeble lines in the Fraunhofer spectrum, if present at all.

(5.) All the coronal rings recorded were most intense in the brightest coronal regions near the sun's equator as depicted by the coronagraph.

(6.) The strongest coronal line, 1474 K, is not represented in the spectrum of the chromosphere and prominences, while H and K do not appear in the spectrum of the corona, although they are the most intense radiations in the prominences.

(7.) A comparison of the results with those obtained in previous eclipses confirms the idea that 1474 K is brighter at the maximum than at the minimum sun-spot period.

(8.) Hydrogen rings were not photographed in the coronal spectrum of 1893.

(9.) D_3 was absent from the coronal spectrum of 1893, and reasons are given which suggest that its recorded appearance in 1882 was simply a photographic effect due to the unequal sensitiveness of the isochromatic plate employed.

* 'Roy. Soc. Proc.,' 1879, vol. 28, p. 13.

(10.) There is distinct evidence of periodic changes of the continuous spectrum of the corona.

(11.) Many lines hitherto unrecorded in the chromosphere and prominences were photographed by the prismatic cameras.

(12.) The preliminary investigation of the chemical origins of the chromosphere and prominence lines enables us to state generally that the chief lines are due to calcium, hydrogen, helium, strontium, iron, magnesium, manganese, barium, chromium, and aluminium. None of the lines appears to be due to nickel, cobalt, cadmium, tin, zinc, silicon, or carbon.

(13.) The spectra of the chromosphere and prominences become more complex as the photosphere is approached.

(14.) In passing from the chromosphere to the prominences some lines become relatively brighter but others dimmer. The same line sometimes behaves differently in this respect in different prominences.

(15.) The prominences must be fed from the outer parts of the solar atmosphere, since their spectra show lines which are absent from the spectrum of the chromosphere.

(16.) The absence of the Fraunhofer lines from the integrated spectra of the solar surroundings and uneclipsed photosphere shortly after totality need not necessarily imply the existence of a reversing layer.

(17.) The spectrum of the base of the sun's atmosphere, as recorded by the prismatic camera, contains only a small number of lines as compared with the Fraunhofer spectrum. Some of the strongest bright lines in the spectrum of the chromosphere are not represented by dark lines in the Fraunhofer spectrum, and some of the most intense Fraunhofer lines were not seen bright in the spectrum of the chromosphere. The so-called "reversing layer" is, therefore, incompetent to produce the Fraunhofer spectrum by its absorption.

(18.) Some of the Fraunhofer lines are produced by absorption taking place in the chromosphere, while others are produced by absorption at higher levels.

(19.) The eclipse work strengthens the view that chemical substances are dissociated at solar temperatures.

I have finally to express my thanks to Messrs. FOWLER and SHACKLETON, not only for the admirable manner in which they performed the duties entrusted to them in securing the photographic records of the eclipse spectra, as will be gathered by a perusal of their reports, but for assistance in the preparation of the present memoir. Mr. FOWLER has generally assisted in the discussion of the photographs, and Mr. SHACKLETON is mainly responsible for the determination of wave-lengths. Messrs. BAXANDALL and BUTLER have also rendered assistance in various ways, and the photographic enlargements have been made by Corporal HASLAM, R.E.

TABLE I.—List of Chromosphere and Prominence Lines.

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			ntensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 5 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
3602	..	..	..	..	Trace	..	..	2
3607	..	..	..	..	Trace	..	..	1
3609	..	..	..	..	1	..	..	1
3613·8	..	..	..	..	1	1	..	2
3619·0	..	..	..	..	1	1	..	1
3625·0	..	..	..	..	..	..	..	1
3630·7	..	..	1	..	2	1	..	4
3635·0	..	..	..	..	1	..	..	..
3641·8	..	..	1	..	1	1	..	2
3647	..	..	1	..	1	1	..	1
3650	..	..	..	..	1	1	..	1
3652	..	..	..	..	..	1	..	1
3659	..	..	..	..	..	..	..	1
3662·2	..	..	..	..	..	..	..	2
3669	..	..	..	..	..	..	..	1
3674·2*	..	..	..	..	..	..	..	..
3676·8	..	..	..	..	..	1	..	..
3679·5*	..	..	..	..	..	..	..	..
3681·1	..	..	..	..	2	2	..	..
3683·5	..	..	..	..	1	1	1	..
3685·2	4	4	6	6	8	6	5	6
3686·7	..	..	..	..	..	2	..	..
3691·5	1	1	1	1	2	3	1	1
3697·4	1	1	2	1	3	3	1	2
3704·0	1	2	4	3	3	5	3	3
3711·8	2	3	4	4	4	6	5	3
3715·5	..	..	..	..	..	1	..	..
3718·5	..	..	..	..	2	2	..	..
3721·9	4	4	5	4	5	5	7	4
3728·5	..	..	..	..	1	1	1	..
3734·2	5	5	6	5	6	6	7	5
3737·1	..	..	..	..	3	3	..	1
3741·7	..	..	..	..	2	2	..	1
3745·8	..	..	..	..	2	3	..	..
3748·5*	..	..	..	..	..	..	..	..
3750·2	6	6	6	5	7	7	8	6
3759·6	7	7	7	7	8	8	8	7
3761·6	7	7	7	7	8	8	8	7
3767·0	..	..	..	..	1	..	..	..
3770·8	6	6	6	6	7	8	8	6
3775·2	..	..	..	..	1	1	..	..
3788·4	..	..	..	..	1	1	..	2
3790·6	..	..	..	..	1	..	..	..

* Appears only in Brazilian photographs.

TABLE I.—List of Chromosphere and Prominence Lines—(continued).

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			Intensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 25 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
3793·6	..	..	..	..	1	..	..	..
3798·1	7	7	7	6	7	8	8	7
3811·0	..	..	..	..	1	..	..	..
3813·3	..	..	..	..	1	..	..	..
3815·6	..	..	..	..	1	..	1	2
3816·7	..	..	..	..	1	1	..	..
3820·4	2	2	3	3	3	3	3	2
3824·8* 3826·1*	..	..	1	..	2	2	1	2
3829·5	..	..	1	..	3	2	2	..
3832·6	..	..	2	2	4	3	3	..
3835·54	8	8	8	7	10	8	6	7
3838·3	4	3	3	3	5	3	4	1
3850·7	..	..	..	..	..	..	1	1
3856·5	1	..	..	..	2	2	1	1
3860·0	3	3	2	3	3	3	5	4
3871·7	..	..	..	..	..	..	1	1
3872·9	..	..	..	..	..	..	..	2
3873·5	..	..	..	..	..	1	1	1
3878·7	2	2	1	..	2	2	3	3
3882·5	..	..	..	..	..	..	..	2
3886·5	..	..	..	..	1	..	..	..
3889·14	10	10	9	9	10	10	8	9
3895·6	..	..	..	..	2	2	1	1
3900·7	4	4	2	3	3	2	5	4
3907·7	..	..	..	..	..	..	1	3
3913·5	4	4	2	3	3	3	5	4
3921·4	..	..	..	..	..	..	1	2
3924·2	..	..	..	..	..	..	1	..
3929·4	..	..	..	..	..	..	1	..
3933·86	10	10	10	10	10	10	10	10
3941·5	..	1	..	..	..	..	..	1
3944·2	3	3	2	2	1	2	3	2
3945·2	..	..	..	..	..	..	..	2
3947·8	..	..	..	..	..	..	..	1
3953·1	..	1	1	..	..	..	..	2
3956·8	..	..	..	..	..	..	..	2
3961·7	3	3	2	2	1	2	3	3
3964·7	..	..	..	..	..	..	..	2
3968·62 3970·25	10	10	10	10	10	10	10	10
3974	..	..	..	..	..	..	..	1
3978·0	..	..	..	..	..	..	..	3

* Appears only in Brazilian photographs.

TABLE I.—List of Chromosphere and Prominence Lines—(continued).

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			Intensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 5 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
3982	..	..	..	..	..	..	1	..
3984·2	..	..	..	..	..	..	..	3
3987·0	..	..	..	..	..	..	..	3
3990·1	..	..	..	..	..	..	1	3
3992	..	..	..	..	..	..	..	1
3996 }	..	..	..	..	..	..	..	1
3998 }	..	..	..	..	..	..	..	1
4001	..	..	..	..	..	..	..	1
4005·5	..	..	..	..	..	..	1	3
4007·0	..	..	..	..	..	..	..	1
4012	..	..	..	..	..	..	1	1
4017	..	..	..	..	..	..	..	1
4026·5	8	8	6	5	3	4	8	3
4030·91	1	1	1	1	..	..	3	3
4033·22	1	1	1	1	..	..	3	3
4034·64	1	1	1	1	..	..	3	3
4035·88	1	1	1	1	..	..	3	3
4040·8	..	1	..	..	..	..	..	1
4041·6	..	..	..	..	..	..	3	1
4044·1	..	..	..	..	..	..	..	3
4045·98	5	5	2	2	1	2	5	3
4049·0	..	..	..	..	..	..	..	3
4052·8	1	1	..	..	..	..	..	..
4055·1	1	1	1	..	..	1	3	3
4057·8	1	1	..	..	..	..	..	1
4059·1	..	..	..	..	..	..	..	1
4063·75	3	3	2	2	..	2	5	3
4066·8	..	1	..	..	..	..	..	1
4067·2	..	..	..	..	..	..	..	3
4070·7	..	..	..	..	..	..	..	3
4071·90	3	3	2	1	..	2	5	3
4077·88	8	8	7	6	4	6	8	7
4084·8	1	1	..	1	..	..	..	1
4087·0	1	1	..	1	..	..	..	1
4092·5	1	1	..	1	..	..	..	..
4097	..	..	..	1	..	..	..	1
4101·8	10	10	9	8	6	9	10	10
4107·5	..	..	..	..	..	..	..	1
4110	..	..	..	..	..	..	..	1
4112	..	1	..	..	..	..	..	..
4115	..	..	..	..	..	..	..	1
4118·7	..	..	..	..	..	..	..	1
4121·0	3	3	2	2	1	1	3	1
4123·7	..	..	..	..	..	..	..	1

TABLE I.—List of Chromosphere and Prominence Lines—(continued).

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			Intensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 5 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
4127·9	..	..	..	..	..	..	..	1
4129·8	..	..	..	..	..	..	1	1
4130·1	..	..	..	..	..	..	1	..
4131·4	..	..	..	..	..	..	1	1
4134·6	..	..	..	..	..	..	..	1
4137·2	..	..	..	..	..	..	1	1
4143·7 } 4144·0	3	3	2	..	1	1	3	5
4149·3	..	..	..	..	..	..	1	1
4152·2	..	..	..	..	..	..	..	1
4154·6	..	..	..	..	..	..	..	1
4157·0	..	..	..	..	..	..	1	1
4162·8	3	1	..	..	..	..	1	..
4167·2	3	3	..	..	..	..	..	3
4172·2	1	3	..	..	..	..	1	5
4177·8	1	..	..	..	..	..	3	5
4187·9	..	..	..	..	..	..	3	1
4190·5	..	..	..	..	..	..	1	..
4191·5	1	..	..	..	..	..	..	1
4198·8	..	1	..	..	..	..	1	1
4202·2	1	1	..	..	..	..	1	..
4205·2	..	..	..	..	..	..	1	1
4210·5	..	1	..	..	..	..	1	1
4215·69	8	7	6	5	2	4	8	7
4217·5	1	..	..	..	..	..	..	..
4219·4	1	..	..	..	..	..	..	1
4224·3	..	..	..	..	..	..	..	3
4226·89	7	5	4	3	2	3	7	5
4233·8	3	3	1	..	..	..	3	5
4236·4	1	..	..	..	..	..	1	1
4247·0	5	5	4	3	1	3	5	5
4254·8	3	3	2	..	..	1	3	1
4256	..	..	..	..	..	..	..	1
4258	..	..	..	..	..	..	..	1
4260·5	1	1	..	..	..	..	3	1
4264·5	1	..	..	..	..	1	..	..
4271·2 } 4271·9	1	5	3	..	..	1	5	3
4275·0	3	5	..	..	..	..	1	5
4280·0	..	1	..	..	..	..	..	1
4282·8	..	..	..	..	..	..	1	1
4290·0	3	3	..	..	..	1	5	5
4291·5	..	..	..	..	..	..	..	1
4294·2	3	3	..	1	..	1	3	..

TABLE I.—List of Chromosphere and Prominence Lines—(continued).

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			Intensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 5 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
4299·1	5 }	4 {	3	1	..	1	5	3
4301·0	3 }		..	.	..	..	..	1
4302·9	..	3	..	..	..	..	..	..
4308·0	4	5	2	1	..	1	3	3
4313·2	4	3	..	..	..	..	..	..
4315·2	3	5	..	1	..	1	3	3
4318·8	..	..	..	..	..	..	..	3
4321·0	..	1	..	..	..	..	3	3
4323·5	..	3	..	..	..	..	3	..
4325·8	3	5	..	1	..	1	..	3
4328	..	1	..	..	..	..	..	..
4331·0	..	..	..	..	..	..	..	3
4334	..	3	..	..	..	..	..	1
4340·66	10	10	10	9	8	10	10	10
4352·0	1	3	..	..	..	..	3	3
4352·9	..	1	1	..	..	..	..	..
4359·8	1	3	..	..	..	..	1	1
4374·2	1	5	1	..	..	1	3	5
4376·1	3	3	..	..	..	..	3	..
4383·8	5	5	2	1	1	1	5	5
4388·5	5	3	2	1	1	1	1	1
4394·2 } 4395·2 }	7	5	3	3	1	2	5	5
4398·7	..	1	..	..	..	..	..	1
4400·3	1	..	..	..	..	..	1	1
4404·92	3	2	1	1	..	..	3	2
4408·5	..	1	..	..	..	..	..	1
4415·3	3	3	1	..	..	1	3	3
4418·0	..	1	..	..	..	..	..	1
4422·8	..	1	..	..	..	..	..	..
4425·6	1	1	..	..	..	..	..	3
4435·2	..	1	1	1	..	1	..	3
4444·0	5	5	3	1	..	2	3	3
4447·5	..	..	..	..	..	..	..	1
4455·0	..	..	..	..	..	..	..	1
4461·8	..	1	..	..	..	1	..	..
4471·8	10	10	8	6	4	6	8	5
4480	..	..	..	..	..	..	1	..
4482·2	..	..	..	..	..	..	..	1
4490·5	..	..	..	..	..	..	1	..
4494·6	..	..	..	..	..	1	..	..
4499·1 } 4501·3 }	5	5	3	1	..	2	3	5
4507	..	..	..	..	..	..	..	1

TABLE I.—List of Chromosphere and Prominence Lines—(continued).

Wave-length.	Intensities in Prominence No. 3.				Intensities in Prominence No. 19.			Intensities at cusp.
	Photo. 7.	Photo. 8.	Photo. 9.	Photo. 10.	Photo. 19.	Photo. 20.	Photo. 21.	Photo. 22.
	Exp. Inst. 3″·7 (1660 miles).	Exp. Inst. 4″·4 (2000 miles).	Exp. 5 secs. 6″·7–8″·5 (3000–3800 miles).	Exp. 25 secs. 12″·2–21″·5 (5480–9600 miles).	Exp. 25 secs. 18″·5–9″·3 (8251–4126 miles).	Exp. 20 secs. 8″·14–4″·44 (3630–1980 miles).	Exp. Inst. 3″·7 (1650 miles).	Exp. 5 secs. Base.
4514·5	..	1	1	..	..	..	..	1
4518·6	..	1	..	..	..	..	..	..
4522·9	2	2	1	..	..	..	..	..
4525·6	..	..	..	..	..	..	..	1
4529	..	..	..	..	..	..	..	1
4534·2	5	5	3	2	..	1	3	2
4549·7	5	5	3	2	..	1	5	3
4554·2	..	..	..	..	..	} 1 (4554·2 and 4556·2)	5	{ 1
4556·2	3	3	..	..	..			1
4565·8	4	4	1	1	..	1	3	3
4569	..	..	..	..	..	..	..	1
4572·2	5	5	2	2	..	1	3	1
4576·5	..	1	..	..	..	..	..	1
4581·7	..	1	..	..	..	..	..	..
4584·0	3	1	..	..	..	..	1	.
4588·2	..	1	..	..	..	..	..	..
4683·8	3	3	1	1	..	..	1	..
4713·2	5	5	4	3	..	1	5	..
4861·5	10	10	10	10	8	9	10	10
4922·1	3	3	4	2	..	..	4	3
4934·2*	..	..	..	..	..	..	..	..
5015·7	..	1	4	2	..	..	3	2
5018·6*	..	..	..	..	..	..	..	..
5047·8*	..	..	..	..	..	..	..	..
5167·57 } 5172·87 }	..	..	3	1	..	..	2	4
5183·79	..	..	4	2	..	..	1	2
5270	..	..	..	..	..	..	..	1
5276	..	..	..	..	..	..	..	1
5363	..	..	..	..	..	..	..	1
5371	..	..	..	..	..	..	..	1
5875·98	..	..	..	..	..	..	..	4
6563·05	..	..	..	..	..	..	..	5

* Appears only in Brazilian photographs.

TABLE II.—Wave-lengths and Intensities of the Lines in the Spectrum of Prominence No. 13.

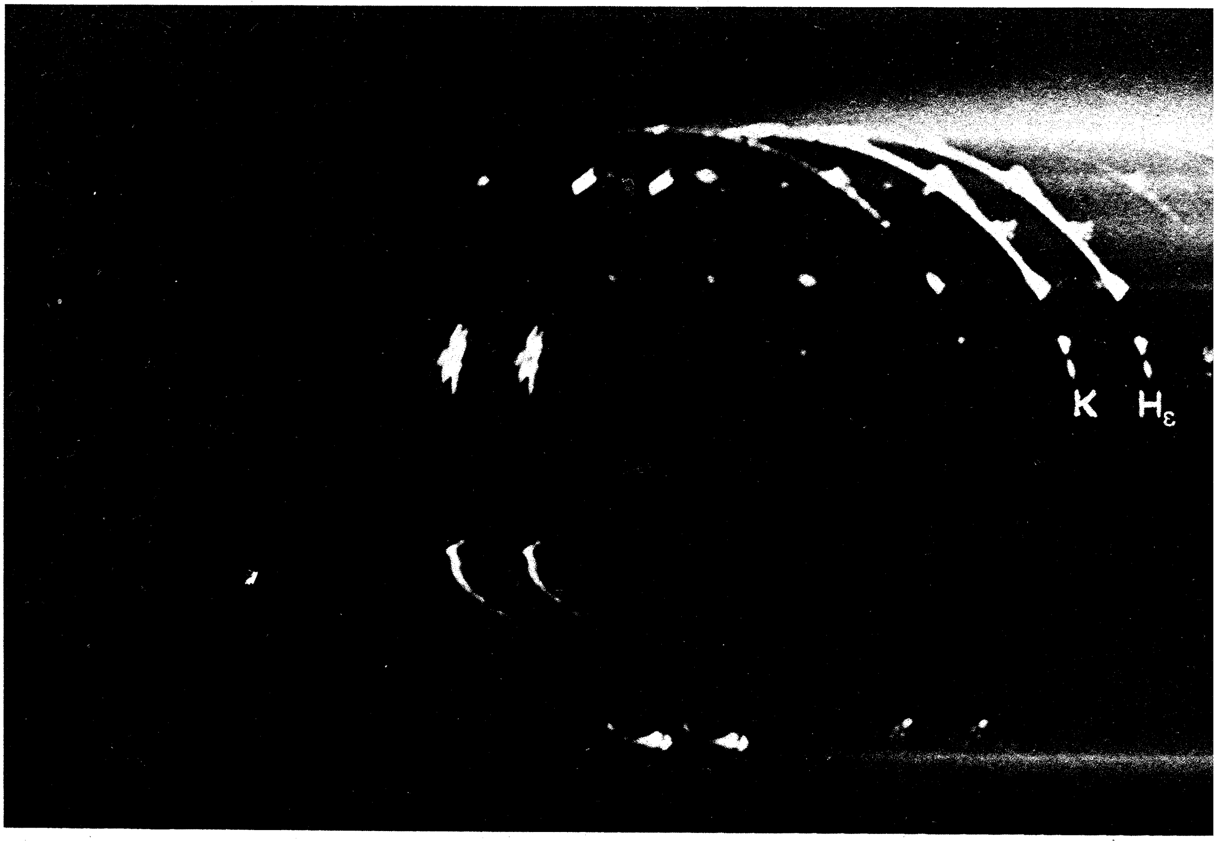
Wave-length.	Intensities in Prominence No. 13.															
	Exposure, instantaneous.					Exposure, 5 secs.				Exposure, 10 secs.			Exposure, 25 secs.			Exposure, 40 secs.
	Photo. 7. 70″. 30,600 miles.	Photo. 8. 69″·6. 30,400 miles.	Photo. 12. 57″·8. 25,300 miles.	Photo. 16. 44″·9. 19,600 miles.	Photo. 21. 25″·9. 11,300 miles.	Photo. 9. 68″·5 to 67″·5. 29,900 to 29,500 miles.	Photo. 13. 55″·5 to 54″·6. 24,200 to 23,800 miles.	Photo. 18. 36″·4 to 35″·4. 15,900 to 15,500 miles.	Photo. 22. 23″·4 to 22″·5. 10,200 to 9,800 miles.	Photo. 11. 60″·5 to 58″·6. 26,500 to 25,600 miles.	Photo. 15. 48″·5 to 46″·6. 21,200 to 20,400 miles.	Photo. 20. 28″·2 to 26″·3. 12,300 to 11,500 miles.	Photo. 10. 65″·6 to 60″·9. 28,700 to 26,600 miles.	Photo. 14. 53″·6 to 48″·9. 23,400 to 21,400 miles.	Photo. 19. 33″·5 to 28″·8. 14,600 to 12,600 miles.	Photo. 17. 44″·5 to 36″·9. 19,400 to 16,100 miles.
3681·1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..
3685·2	..	..	..	..	..	5	3	3	3	1	3	5	3	3	7	5
3691·5	..	..	..	..	..	..	..	1	..	..	1	1	..	1	1	1
3697·4	..	..	..	..	..	1	..	1	1	..	1	1	..	1	1	1
3704·0	..	..	..	..	..	1	1	1	1	..	3	3	1	3	3	1
3711·8	..	..	..	..	..	3	3	3	3	1	3	3	1	3	3	1
3721·9	..	..	..	..	..	3	3	3	3	1	3	3	3	3	5	3
3734·2	..	..	..	..	..	3	3	3	3	3	3	3	3	3	5	3
3750·2	..	..	..	..	..	3	3	3	3	3	3	3	3	3	5	3
3759·6	..	..	..	..	1	5	5	5	5	5	5	5	5	5	7	5
3761·6	..	..	..	..	1	5	5	5	5	5	5	5	5	5	7	5
3770·8	..	..	..	..	..	3	3	3	5	3	3	5	3	3	5	3
3798·1	..	..	..	..	1	5	3	4	5	3	3	5	3	3	7	3
3820·4	..	..	..	..	..	3	..	1	1	1	3	1	1	3	1	1
3835·54	..	..	..	..	3	5	5	5	5	5	5	5	5	5	7	5
3859·8	..	..	..	..	..	1	..	1	..	1	1	1	1	1	1	1
3889·14	3	3	5	3	5	7	8	8	7	7	7	8	7	7	8	8
3933·86	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3968·62	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3970·25	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4026·5	..	..	1	1	5	3	3	3	5	3	3	5	3	3	3	3
4045·98	..	..	..	..	1	..	..	1	..	..	..	1	..	..	..	..
4063·75	..	..	..	..	1	..	..	..	..	..	..	1	..	..	..	..
4077·88	..	..	1	1	5	3	3	3	5	3	3	5	3	3	3	3
4101·8	..	..	5	5	7	5	5	7	7	5	5	7	5	5	7	7
4121·0	..	..	..	..	1	..	..	1	..	..	..	1	..	..	..	1
4144·0	..	..	..	..	1	..	..	1	..	..	..	1	..	..	..	1

TABLE II.—Wave-lengths and Intensities of the Lines in the Spectrum of Prominence No. 13—(continued).

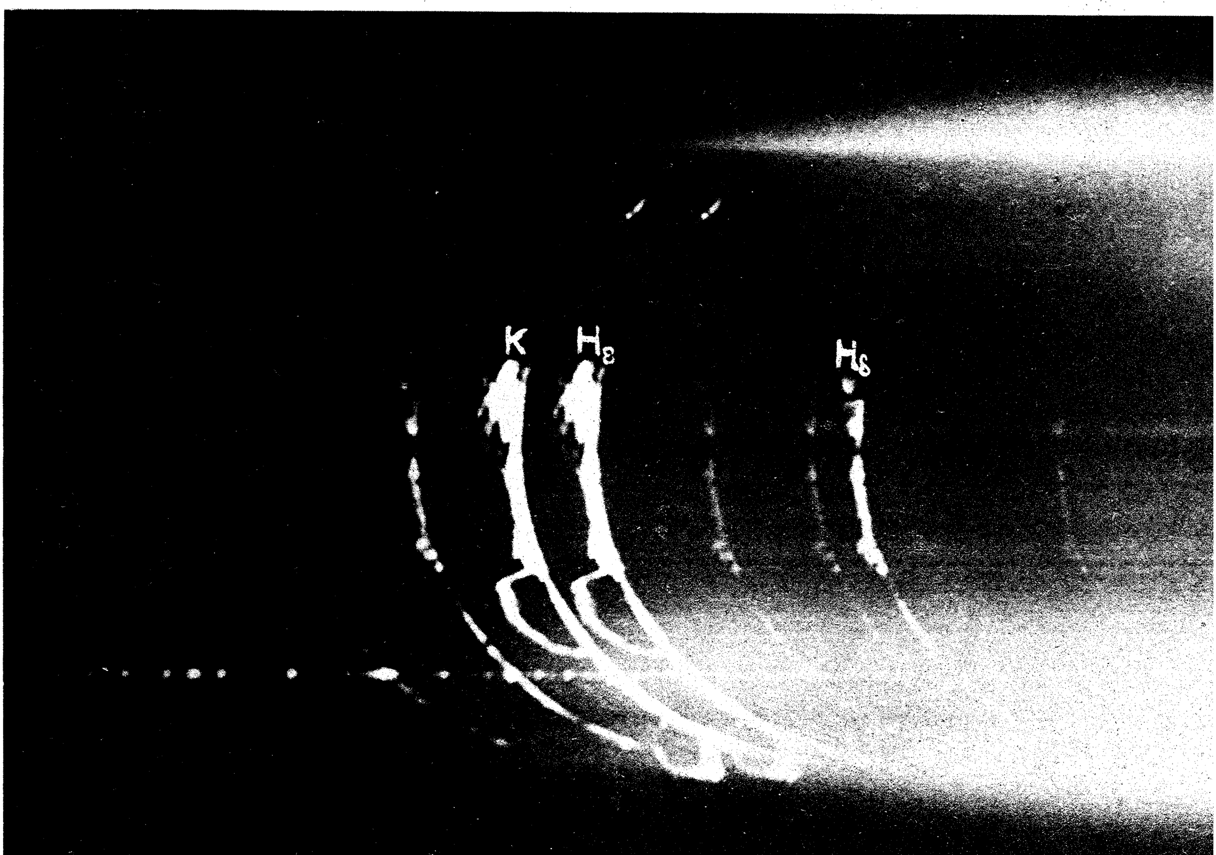
Wave-length.	Intensities in Prominence No. 13.															
	Exposure, instantaneous.					Exposure, 5 secs.				Exposure, 10 secs.			Exposure, 25 secs.			Exposure, 40 secs.
	Photo. 7. 70″. 30,600 miles.	Photo. 8. 69″·6. 30,400 miles.	Photo. 12. 57″·8. 25,300 miles.	Photo. 16. 44″·9. 19,600 miles.	Photo. 21. 25″·9. 11,300 miles.	Photo. 9. 68″·5 to 67″·5. 29,900 to 29,500 miles.	Photo. 13. 55″·5 to 54″·6. 24,200 to 23,800 miles.	Photo. 18. 36″·4 to 35″·4. 15,900 to 15,500 miles.	Photo. 22. 23″·4 to 22″·5. 10,200 to 9,800 miles.	Photo. 11. 60″·5 to 58″·6. 26,500 to 25,600 miles.	Photo. 15. 48″·5 to 46″·6. 21,200 to 20,400 miles.	Photo. 20. 28″·2 to 26″·3. 12,300 to 11,500 miles.	Photo. 10. 65″·6 to 60″·9. 28,700 to 26,600 miles.	Photo. 14. 53″·6 to 48″·9. 23,400 to 21,400 miles.	Photo. 19. 33″·5 to 28″·8. 14,600 to 12,600 miles.	Photo. 17. 44″·5 to 36″·9. 19,400 to 16,100 miles.
4215·69	..	..	1	..	3	1	..	3	3	1	1	3	1	1	1	2
4226·89	..	..	..	..	1	..	..	2	..	..	..	1	..	..	..	..
4233·8	..	..	..	..	1	..	..	1	..	..	..	1	..	..	1	..
4247·0	..	..	..	..	1	..	..	2	..	..	..	1	..	..	..	..
4340·66	..	..	7	5	7	5	5	7	7	5	5	7	5	5	7	7
4376·1	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4383·8	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4394·2	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..
4395·2	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4415·3	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4445·0	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4471·8	..	..	5	3	5	3	3	5	5	3	3	5	3	3	5	5
4501·3	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4534·2	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4549·7	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4556·2	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4683·8	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
4713·2	..	..	..	..	3	..	..	..	..	..	..	1	..	..	..	1
4861·8	..	..	7	5	7	5	5	7	7	5	5	7	5	5	7	7
5875·98	..	..	..	..	..	..	..	5	..	..	..	..	..	..	..	5
6563·05	..	..	..	..	..	..	..	1	..	..	..	..	..	..	3	1

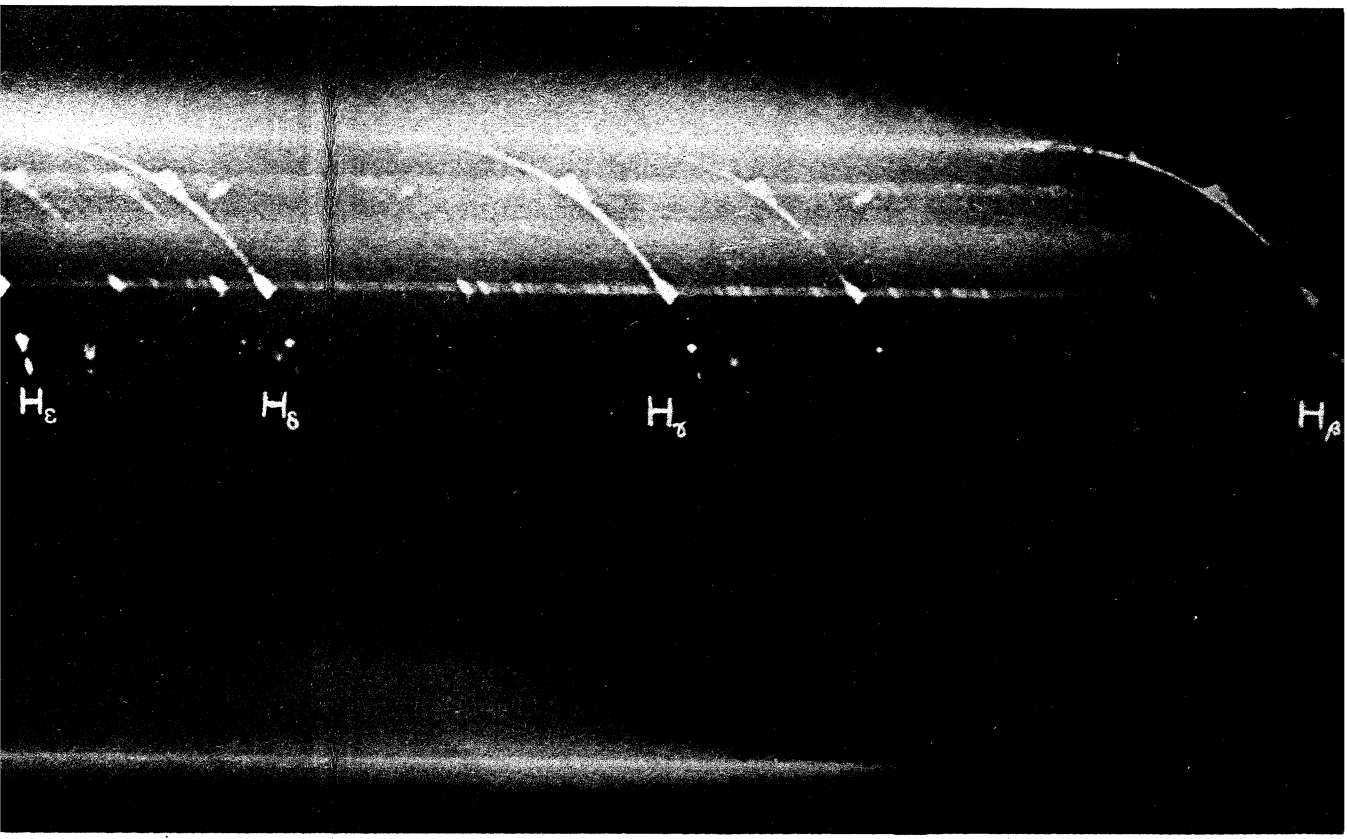
TABLE III.—Spectrum of Chromosphere at top and bottom.

Wave-length.	Intensity in chromospheric arc No. 20. African photo. 21. Above 3″·7.	Intensity at base of chromosphere. (Cusp.)
3734·2	1	5
3750·2	1	6
3759·6	2	7
3761·6	2	7
3770·8	2	6
3798·1	4	7
3835·5	5	7
3838·3	2	1
3889·1	6	9
3900·7	1	4
3913·5	1	4
3933·9	10	10
3968·6 } 3970·2 }	10	10
4026·5	4	3
4030·9	1	3
4046·0	1	3
4063·8	1	3
4071·9	1	3
4077·9	4	7
4101·8	8	10
4121·0	1	1
4144·0	1	5
4215·7	3	7
4226·9	2	5
4233·8	1	5
4247·0	2	5
4340·7	8	10
4383·8	1	5
4394·2	2	5
4444·0	2	3
4471·8	5	5
4501·3	2	5
4534·2	1	2
4549·7	1	3
4683·8	1	..
4713·2	3	..
4861·8	8	10

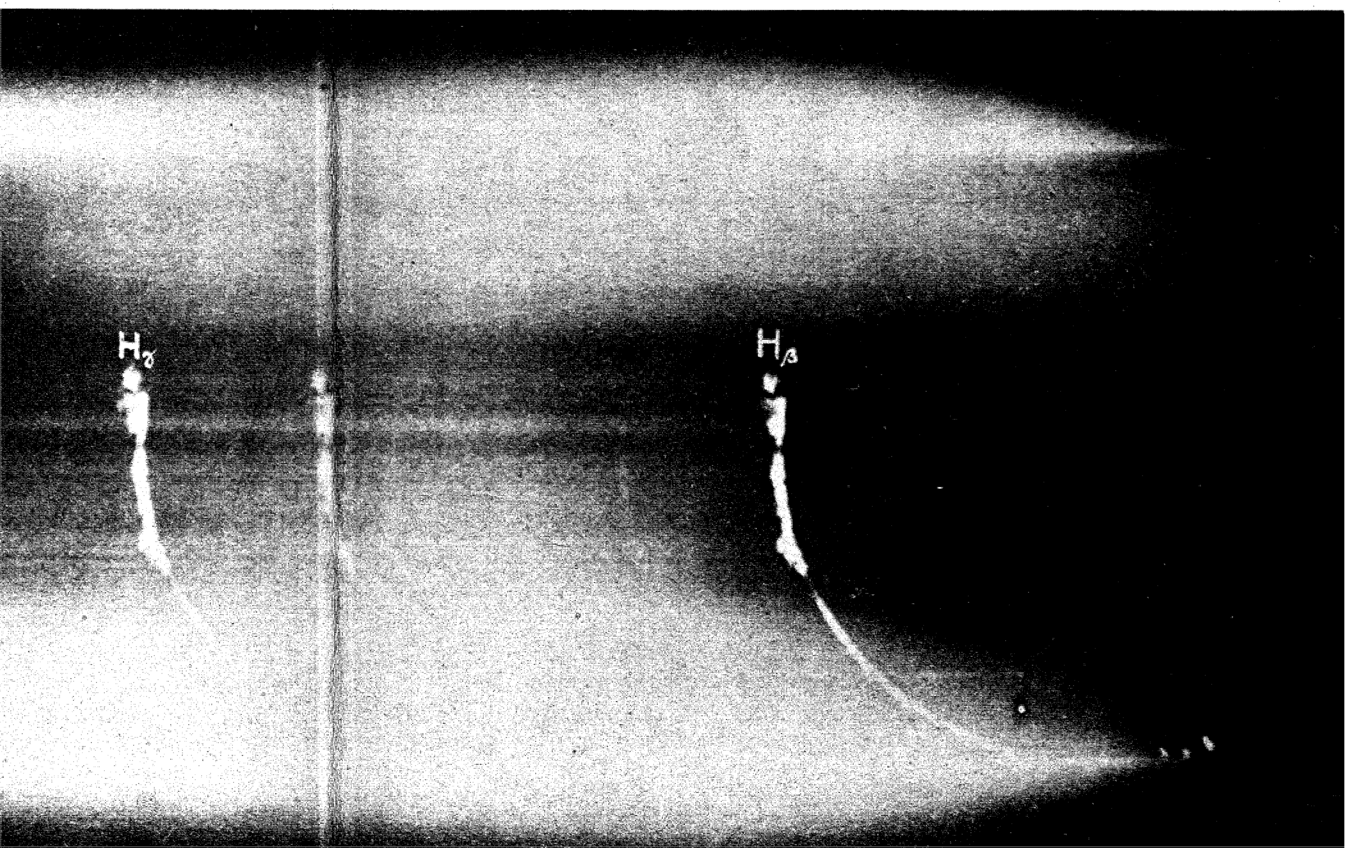


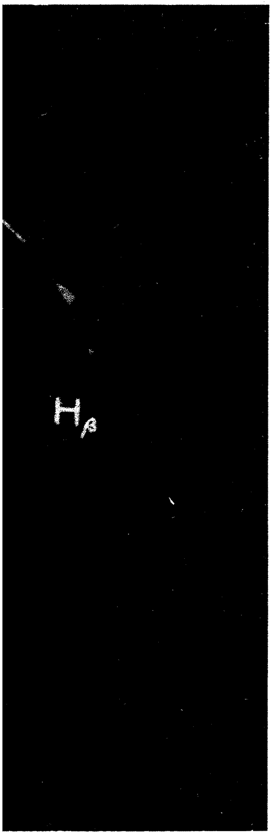
Nº 7. ABOUT 10 SECS. A

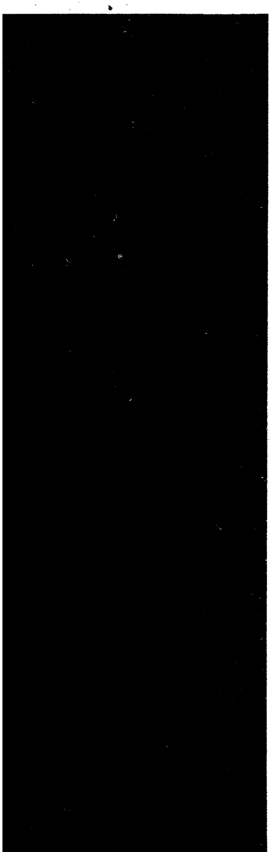


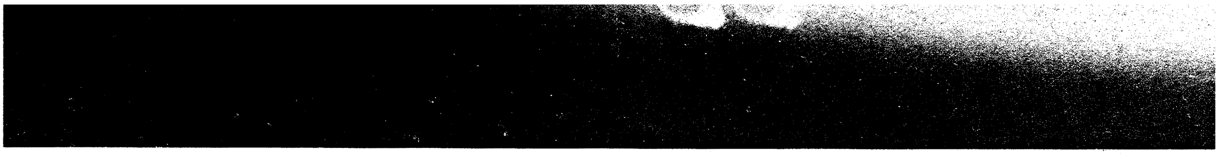


S. AFTER COMMENCEMENT OF TOTALITY

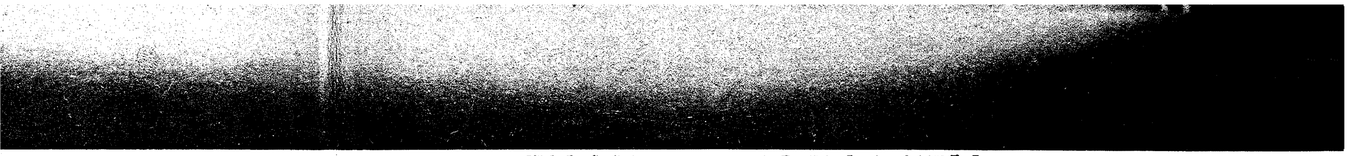



Hβ

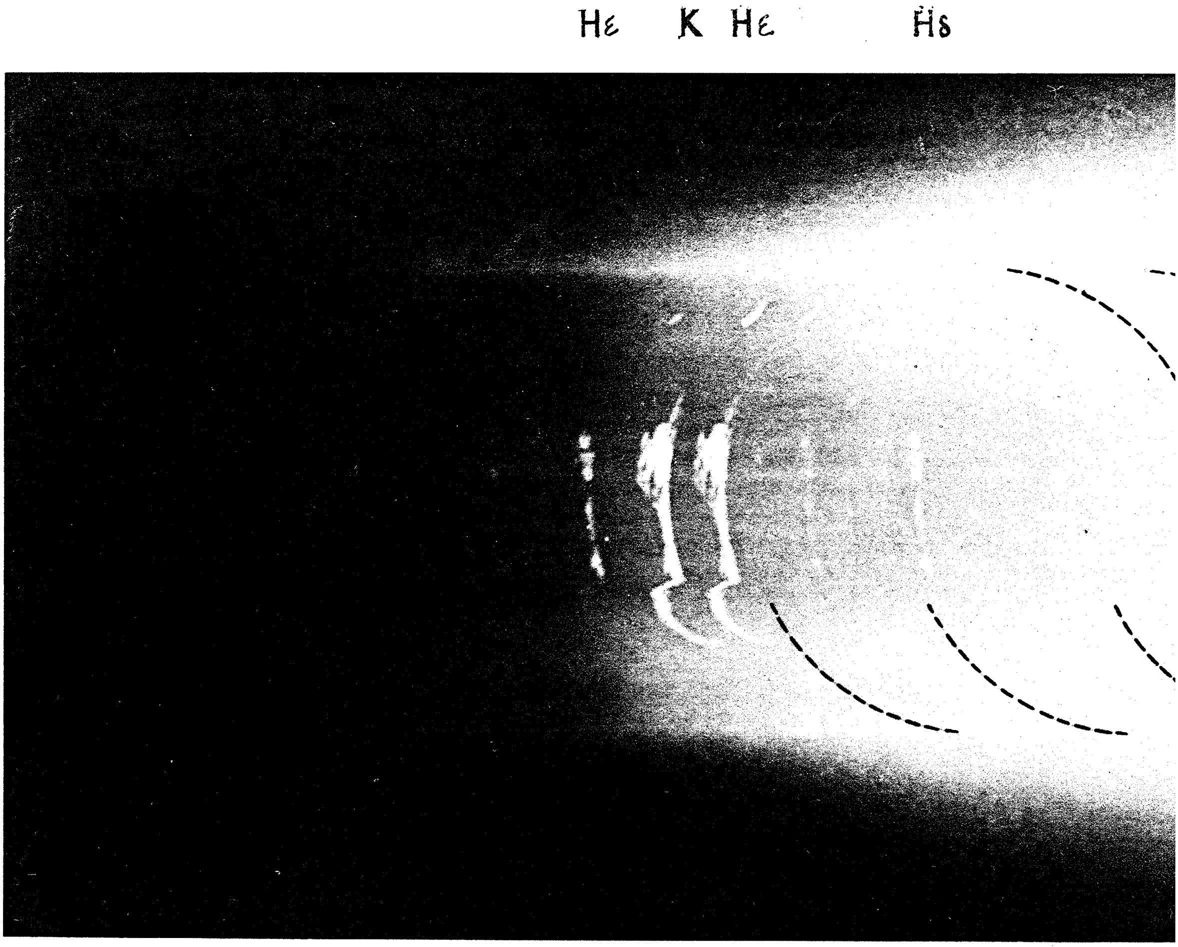




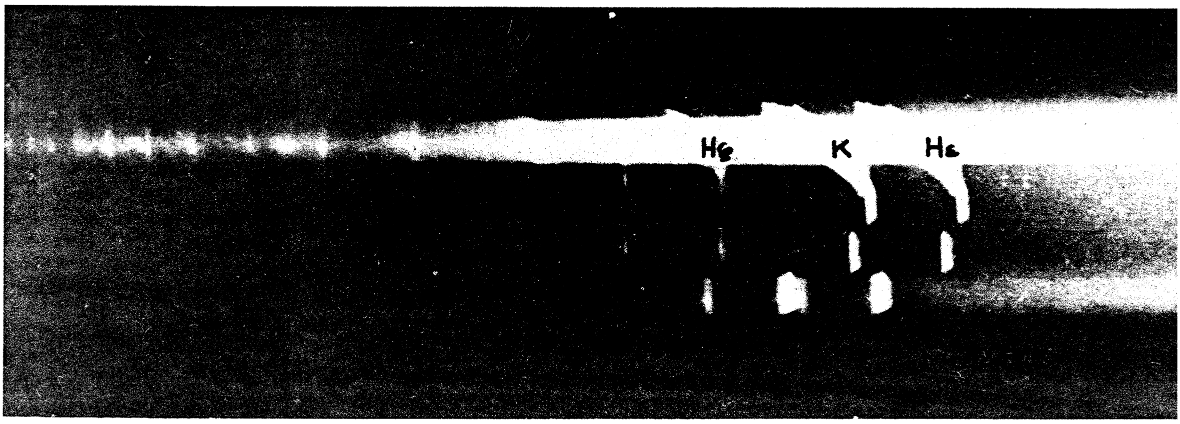
Nº 21 ABOUT 10 SECS



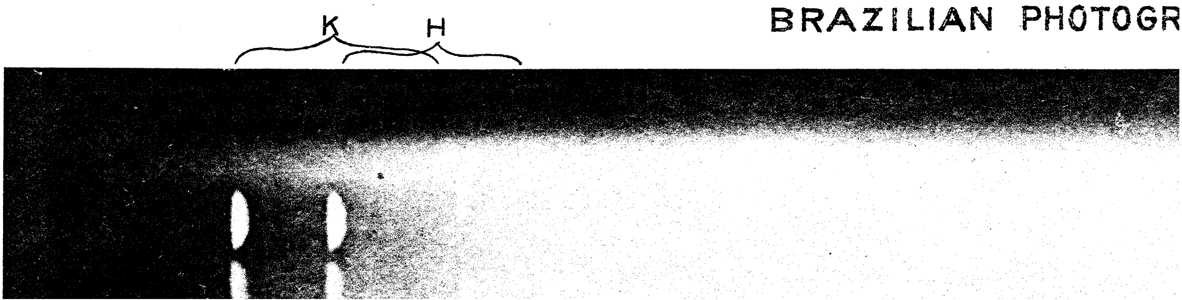
ECS. BEFORE THE END OF TOTALITY

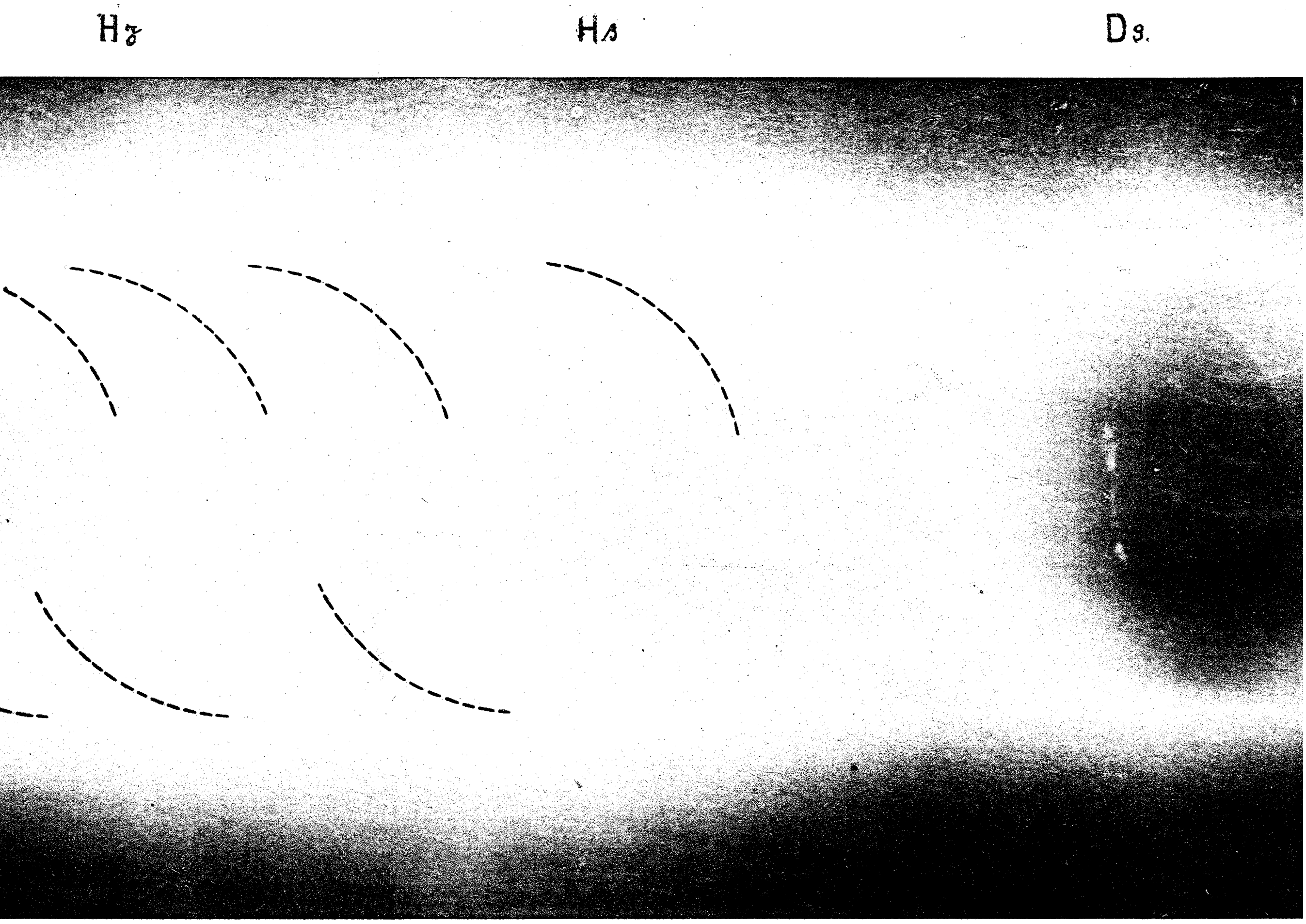


AFRICAN PHOTOGRAPH N°

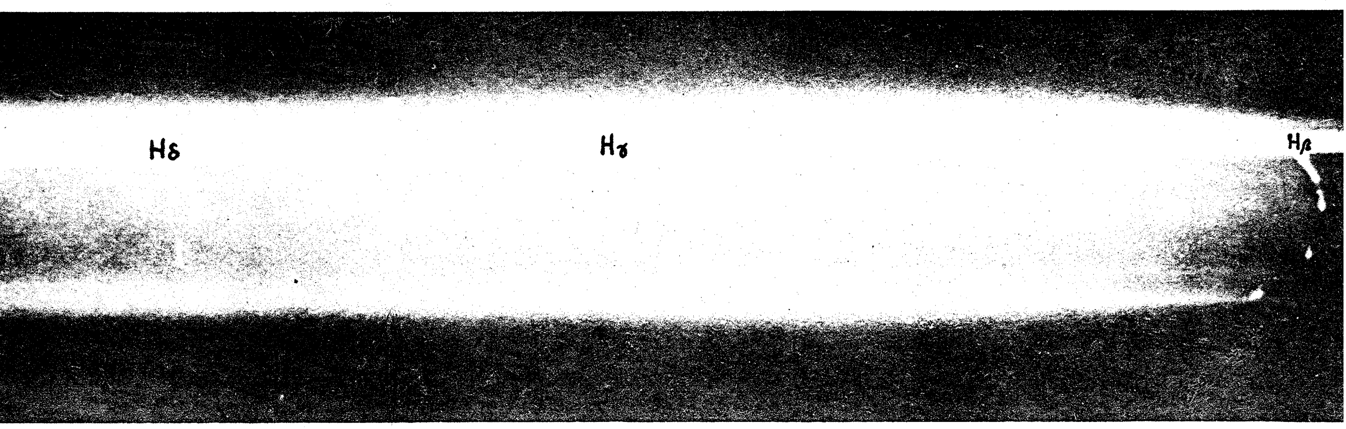


BRAZILIAN PHOTOGR



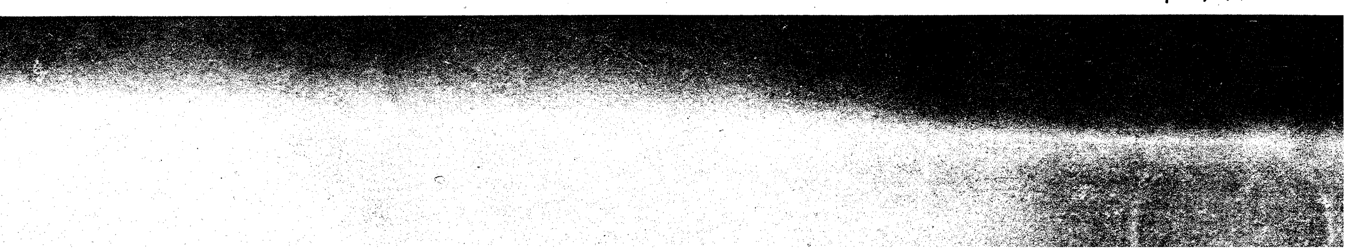


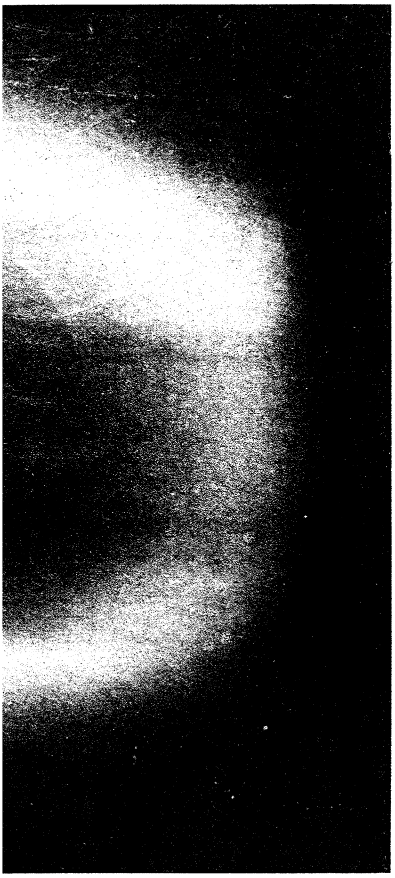
H Nº 17. SHOWING POSITIONS OF CORONAL RINGS.

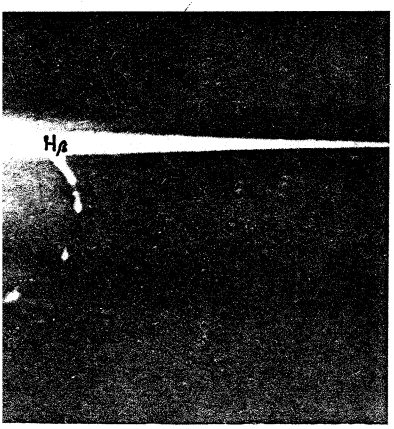


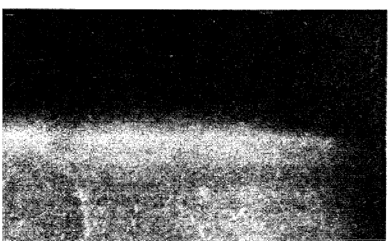
OTOGRAPH Nº 2. COMMENCEMENT OF TOTALITY

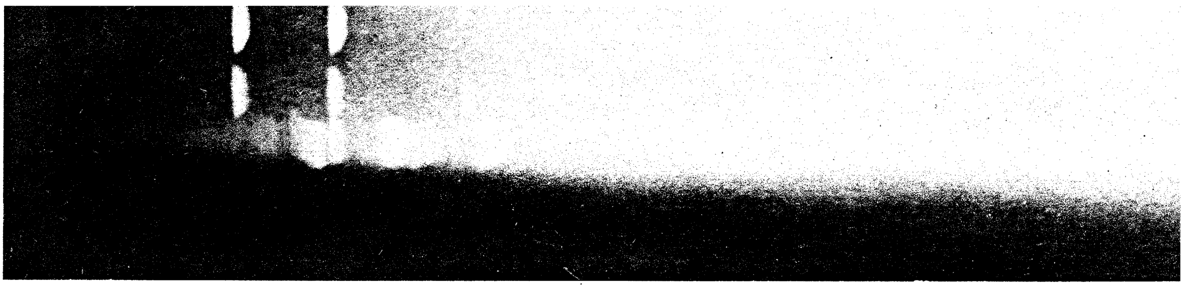
1474 K



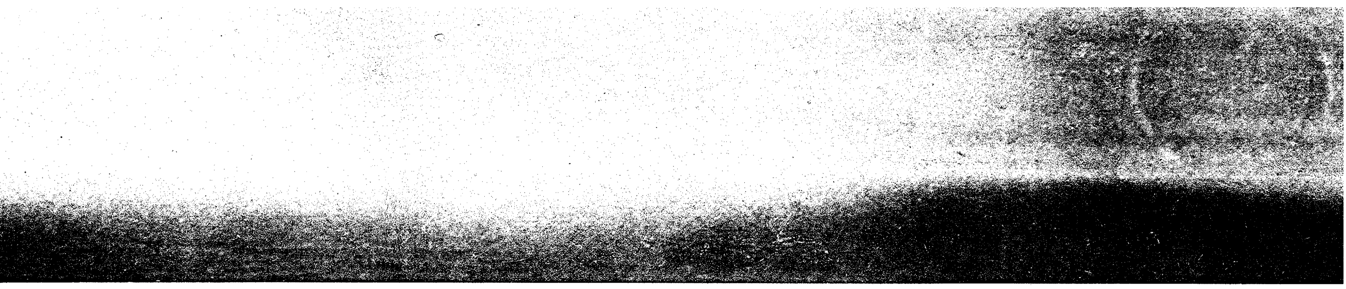



Hβ

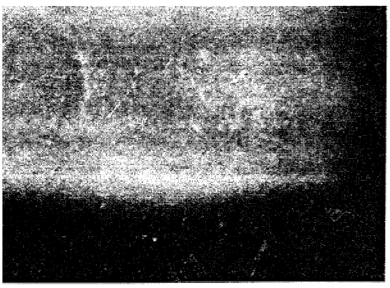


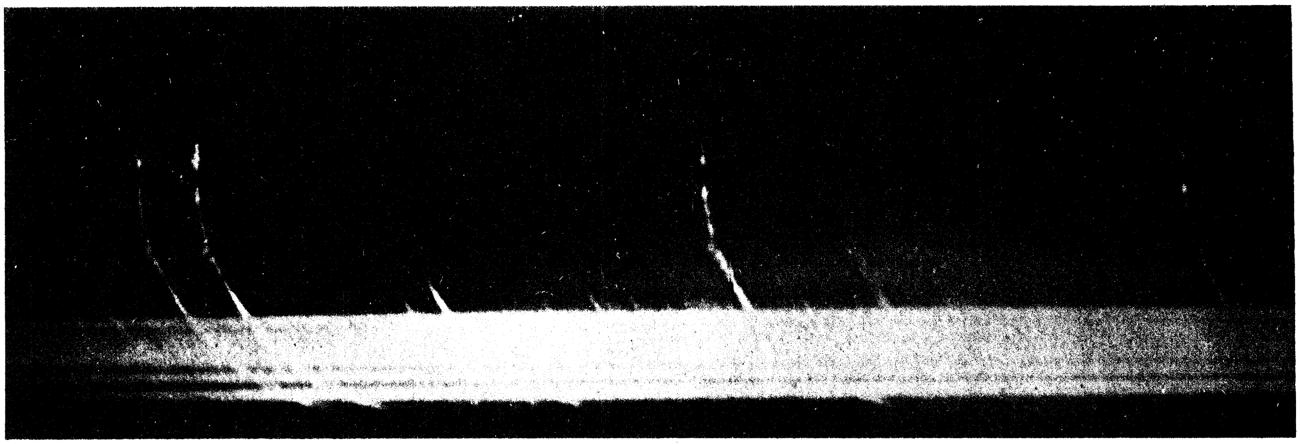


BRAZILIAN PH

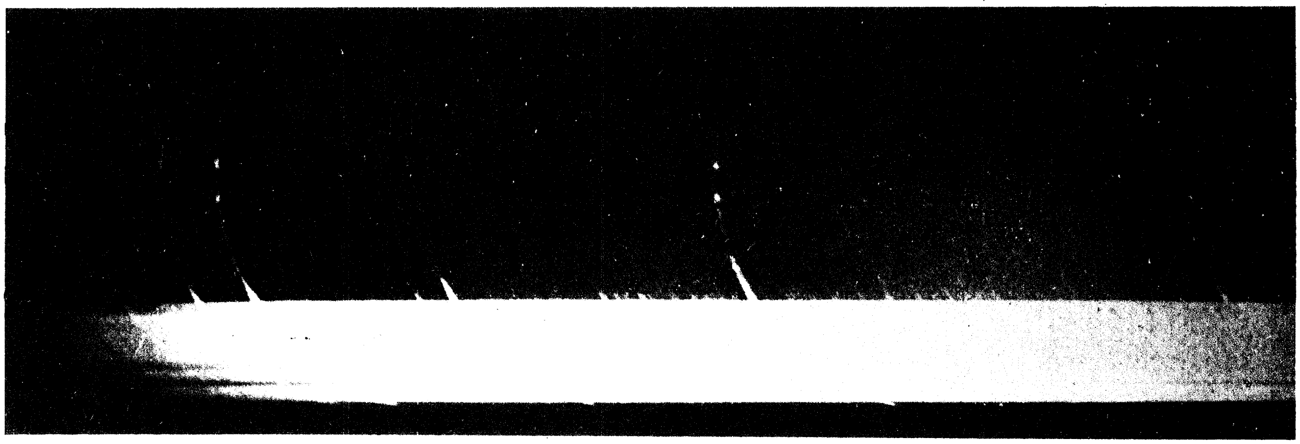


AN PHOTOGRAPH Nº 12. MIDDLE OF TOTALITY

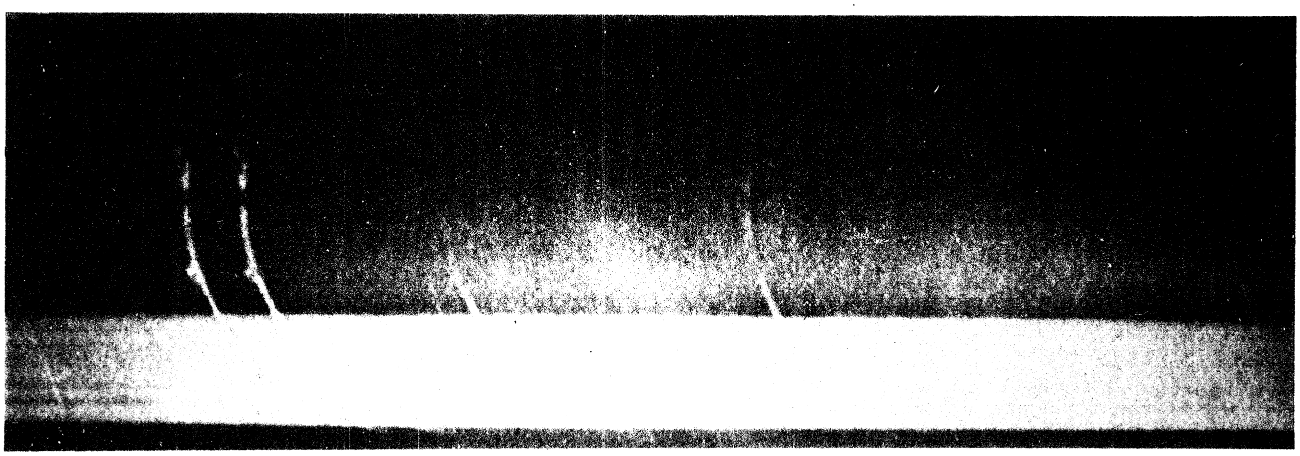




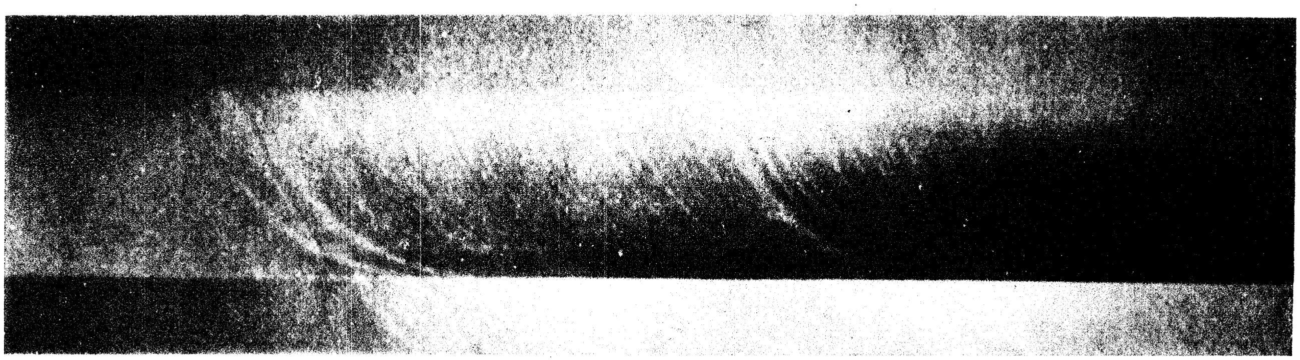
AFRICAN PHOTO No. 22. 3-8 SECONDS AFTER TOTALITY



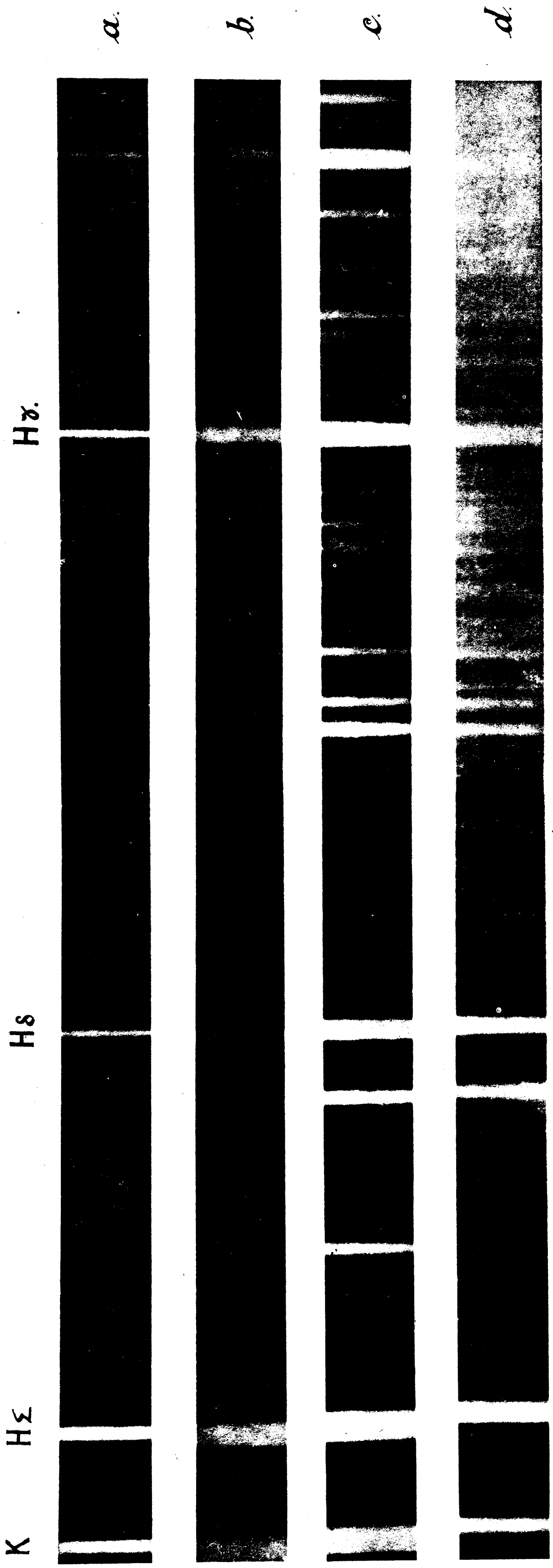
No. 23. 10 SECONDS AFTER TOTALITY



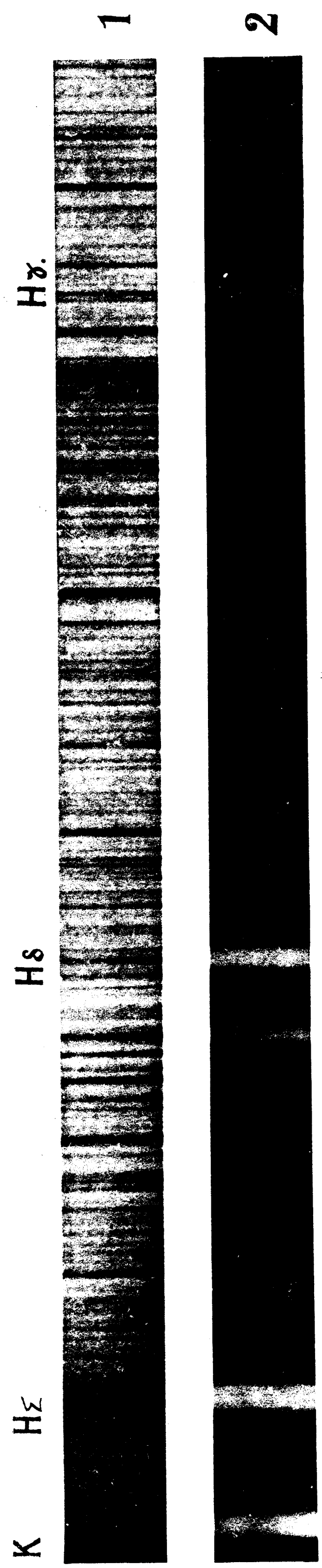
No. 24. 11 SECONDS AFTER TOTALITY



No. 25. 41-49 SECONDS AFTER TOTALITY

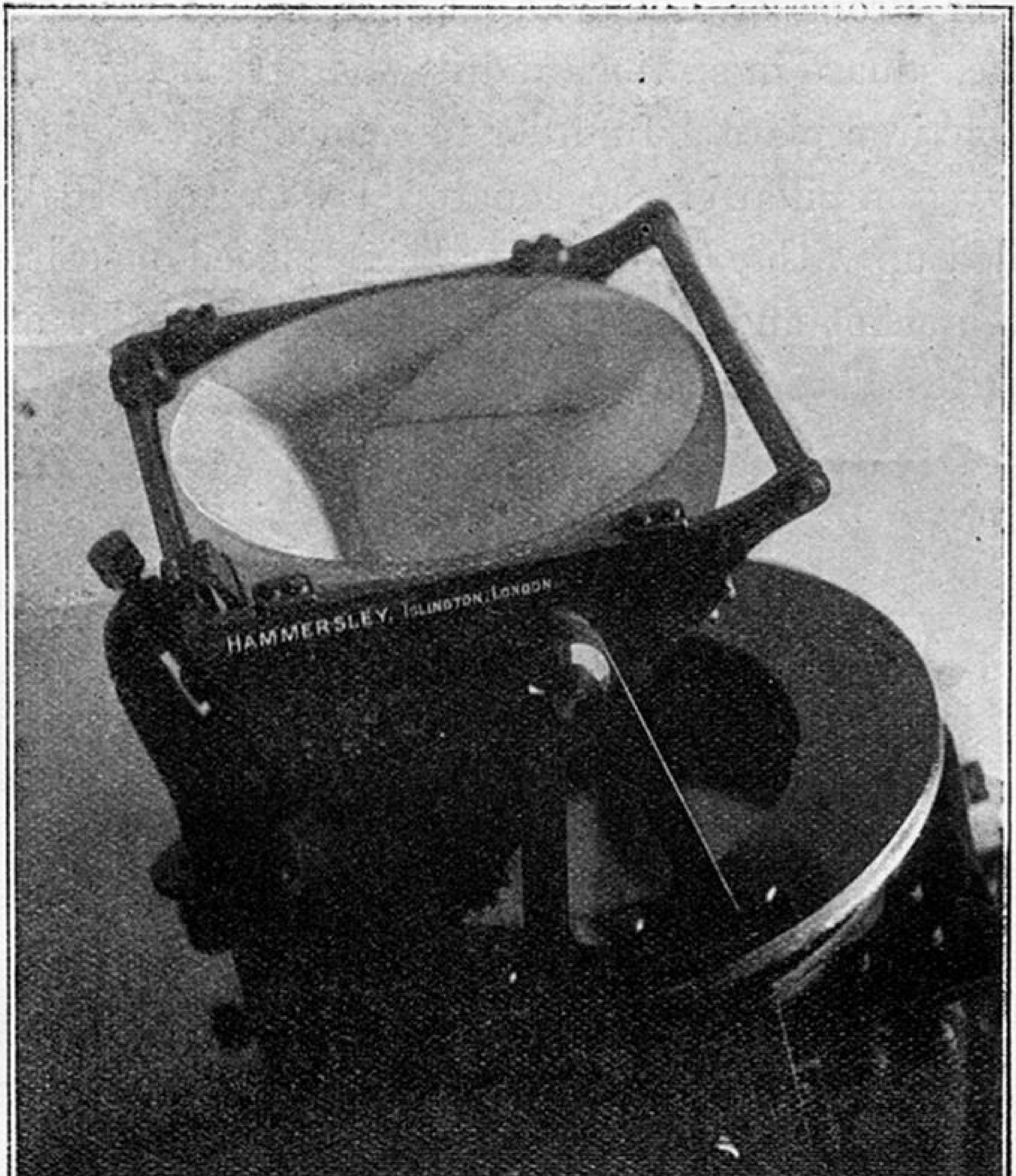


Spectrum of Prominence No. 3. (a) 22"–26" above photosphere; (b) 7"–9", (c) 3".7; compared with spectrum of base of chromosphere (d).



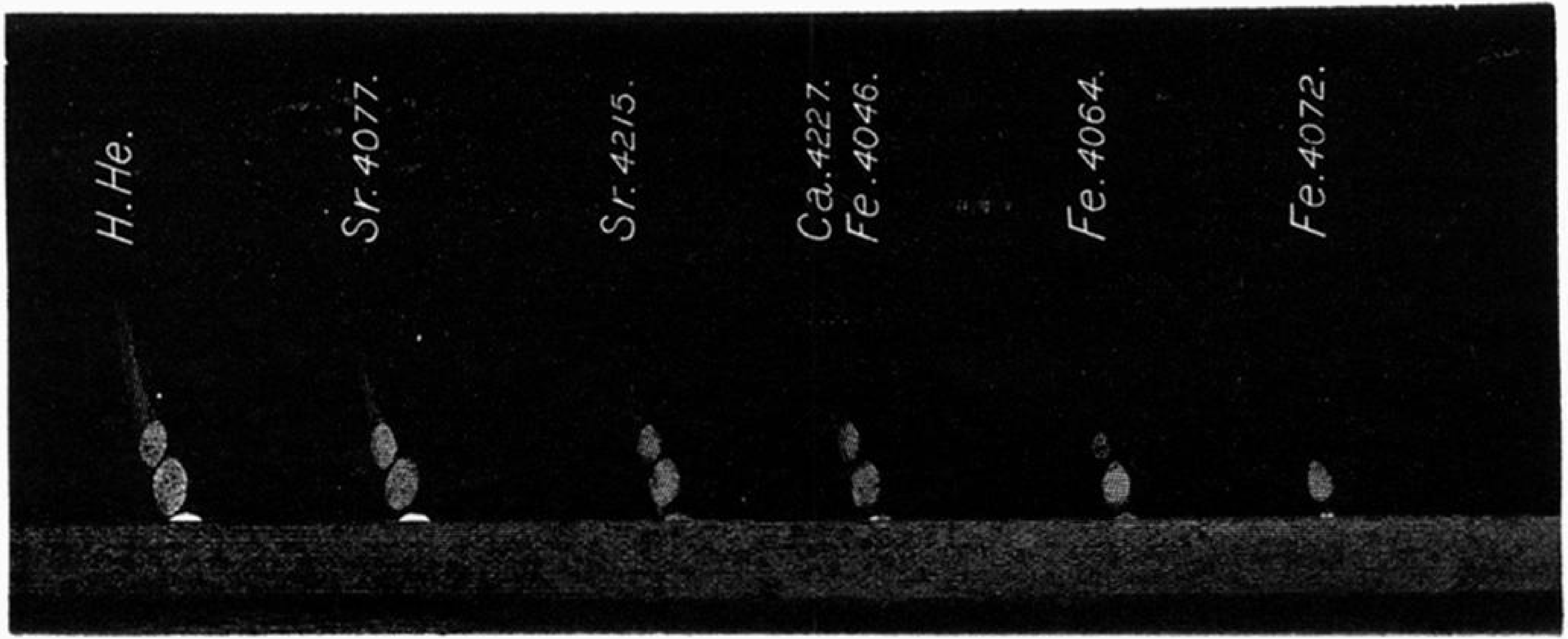
The spectrum of the base of the chromosphere (2) compared with the spectrum of Arcturus (1).

Fig. 2.



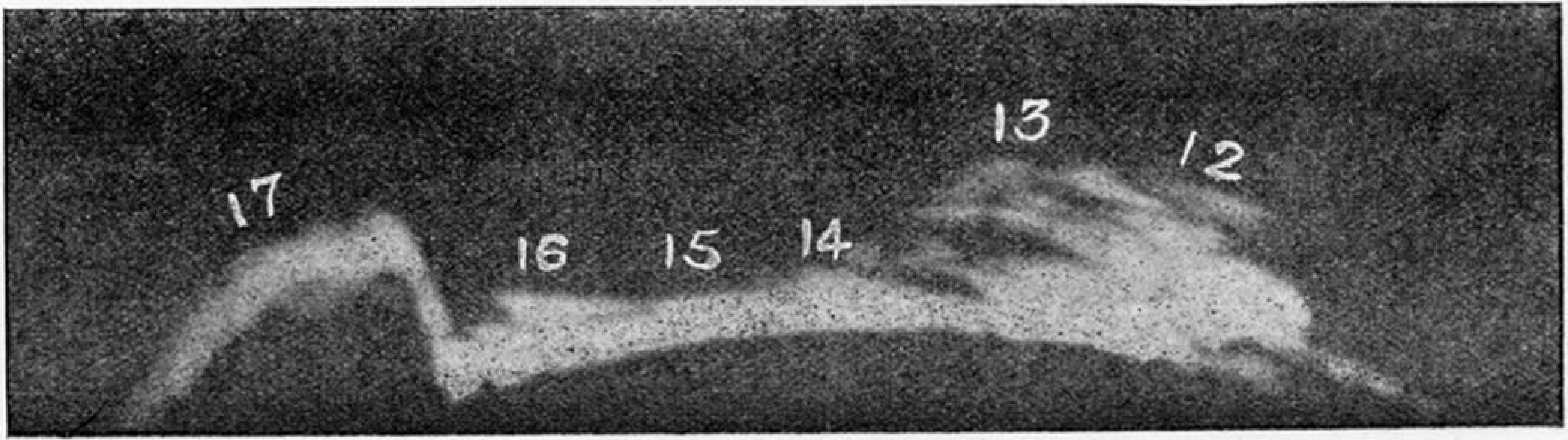
Details of prism mounting.

Fig. 7.



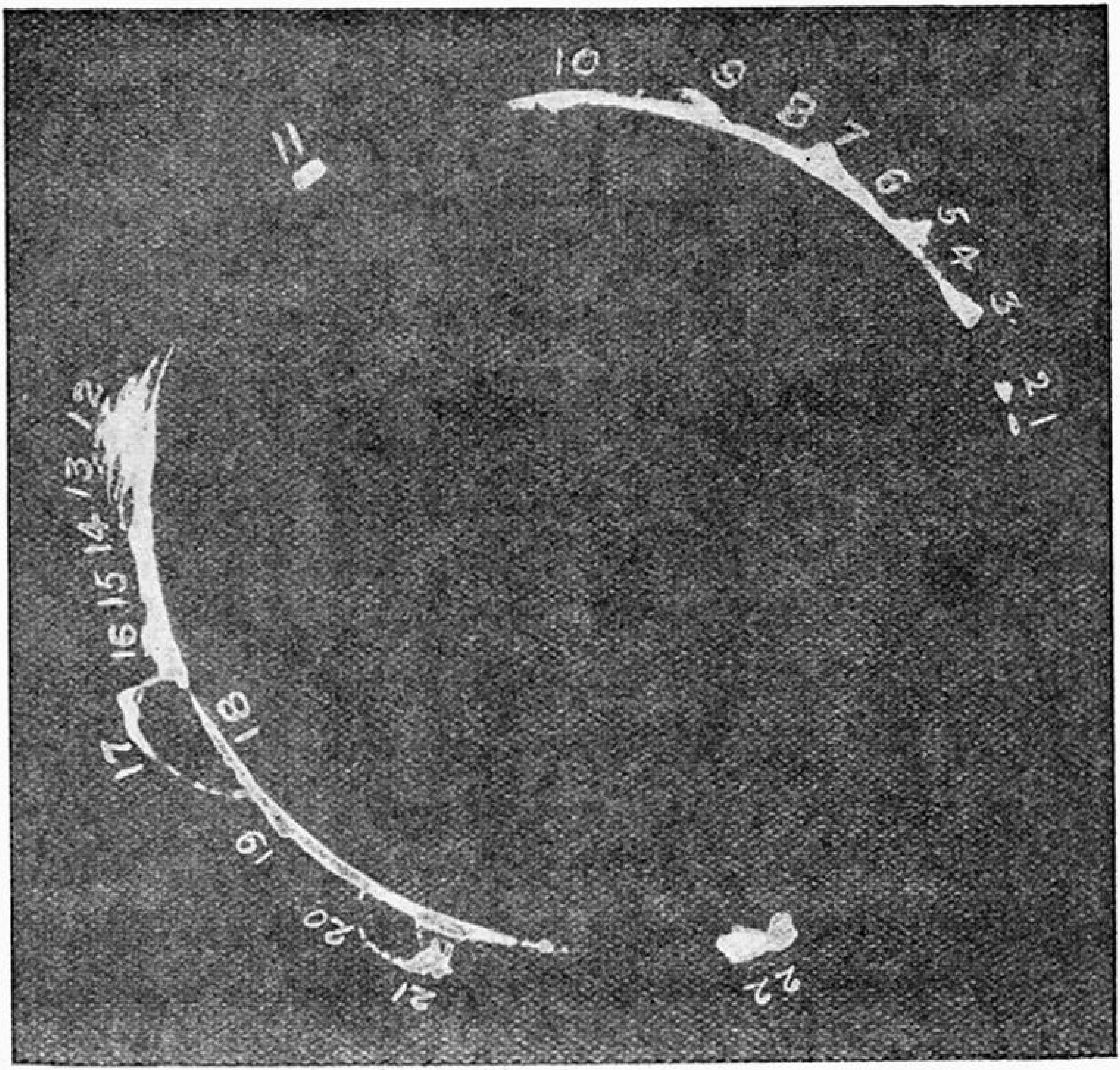
Appearances of bright arcs in spectrum of cusp.

Fig. 9.



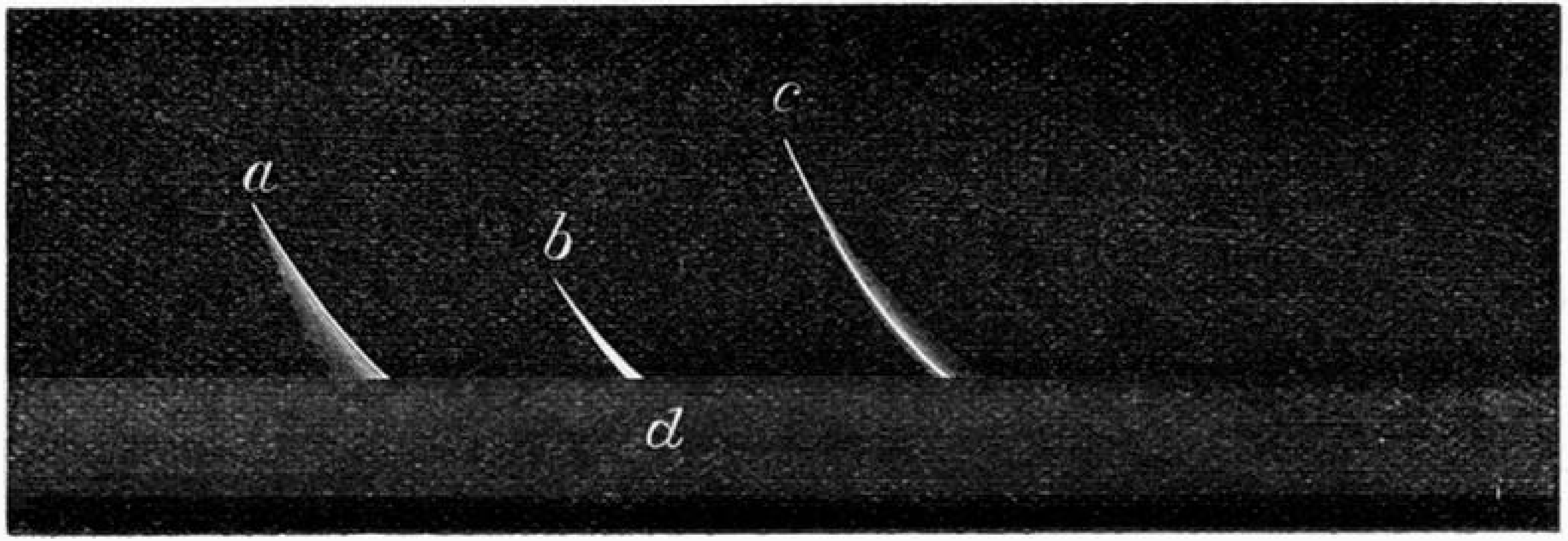
Group of prominences near sun's south pole, April 16, 1893.

Fig. 10.



Chromosphere and prominences depicted in the K radiation of calcium.

Fig. 11.



Possible appearances of bright arcs at cusp in photographs taken out of totality.

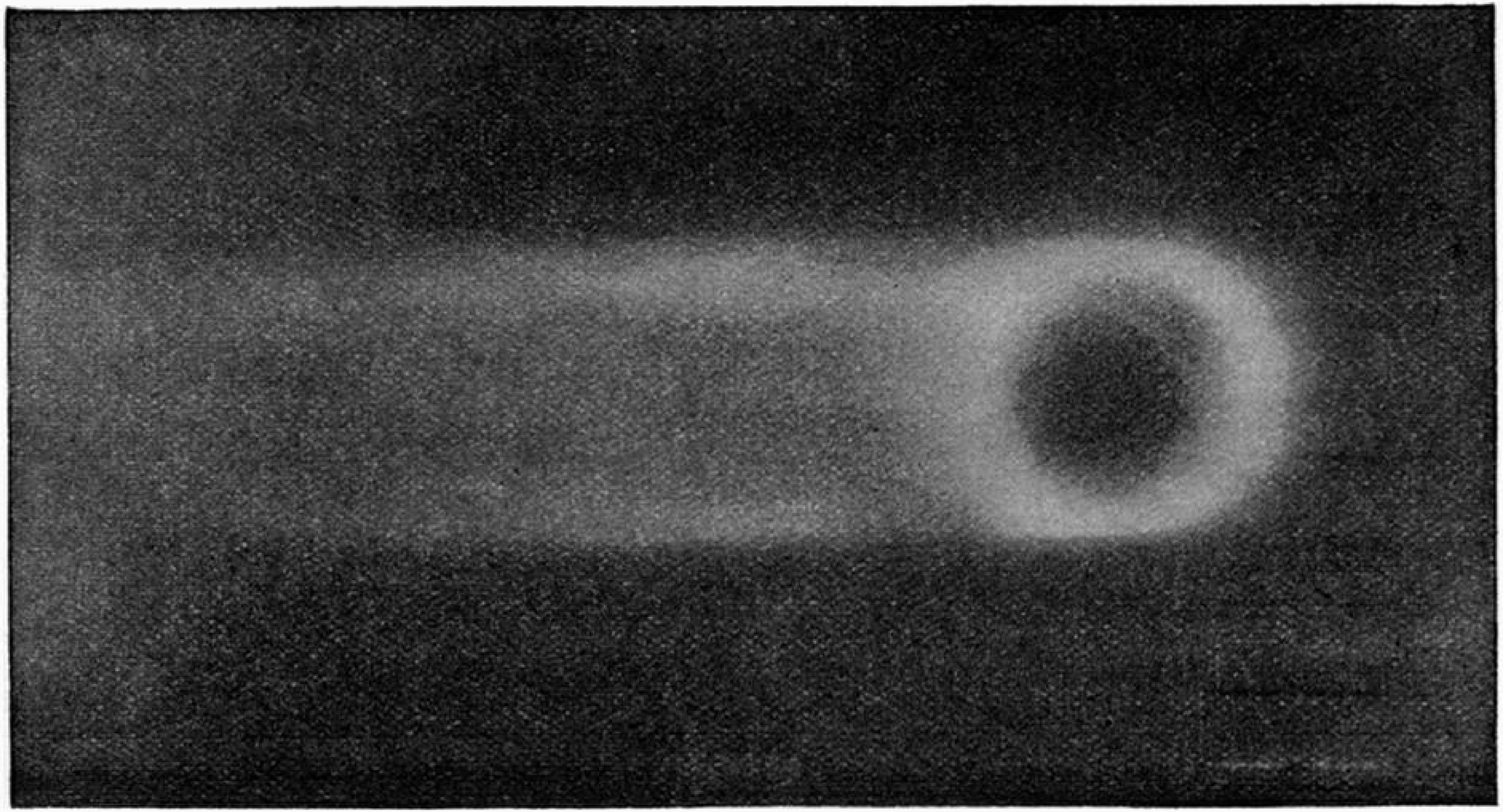
(*a*) Arc due to vapour extending from photosphere outwards, with gradually diminishing brightness.

(*b*) Arc due to a thin layer close to photosphere and equally bright throughout.

(*c*) Arc due to a shell of vapour, concentric with photosphere, but some distance from it.

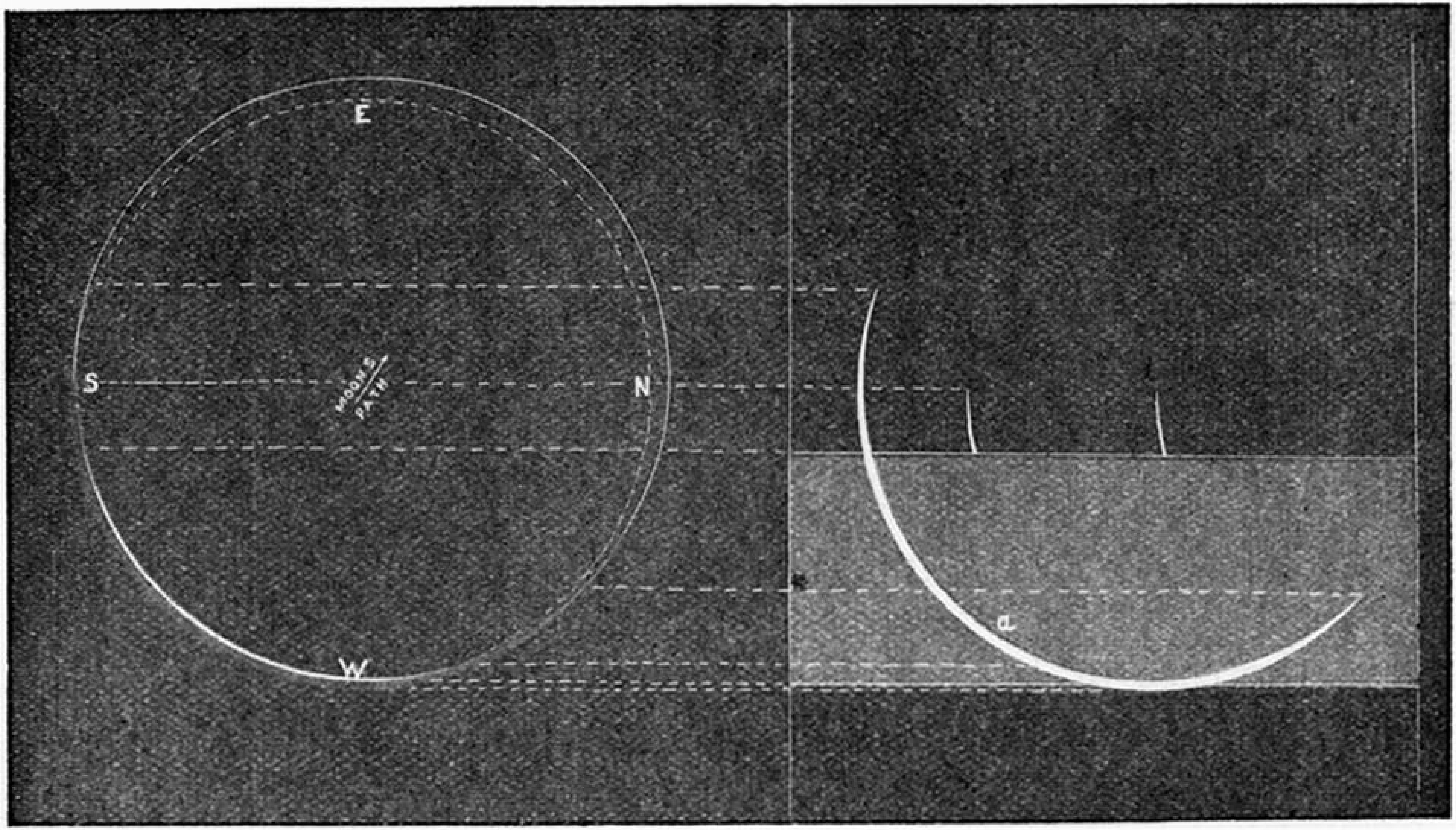
(*d*) Continuous spectrum of photosphere.

Fig. 14.



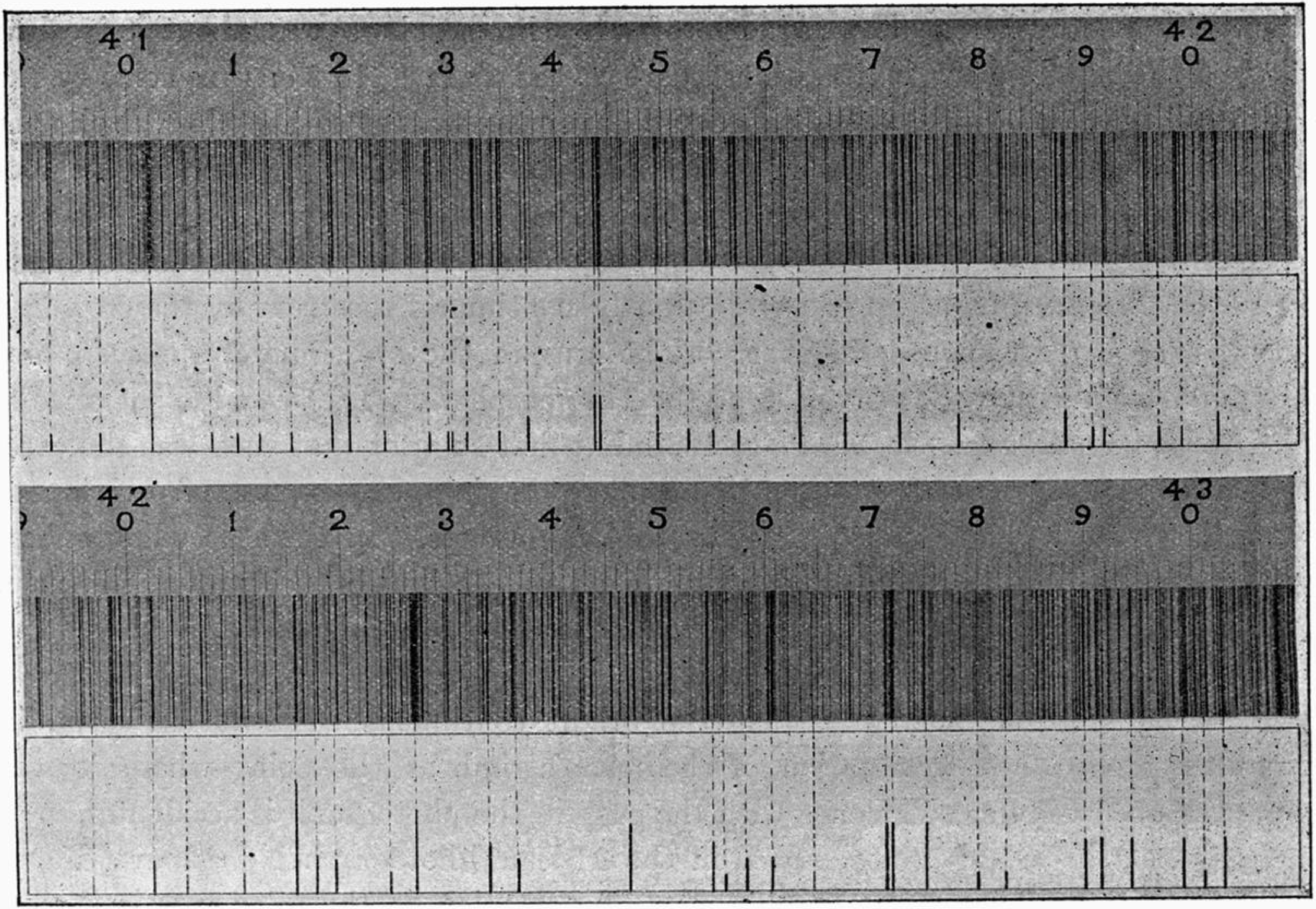
Appearance of continuous spectrum photographed on an isochromatic plate with a ring slit.

Fig. 15.

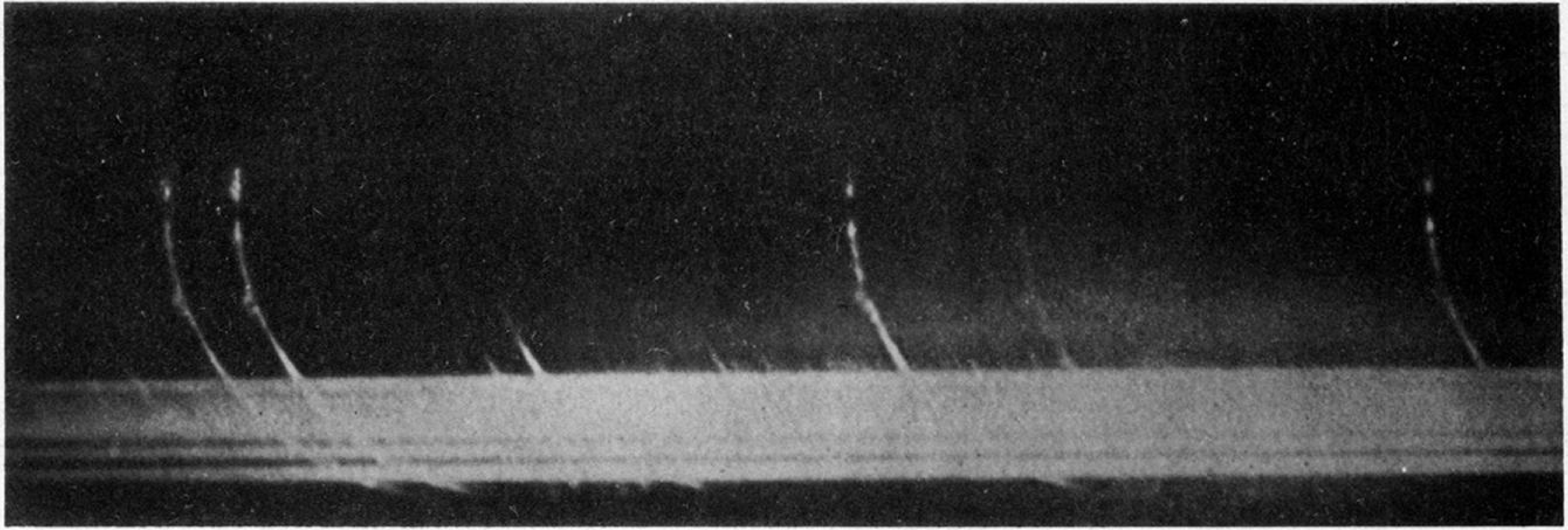


General explanation of photographs taken out of totality.

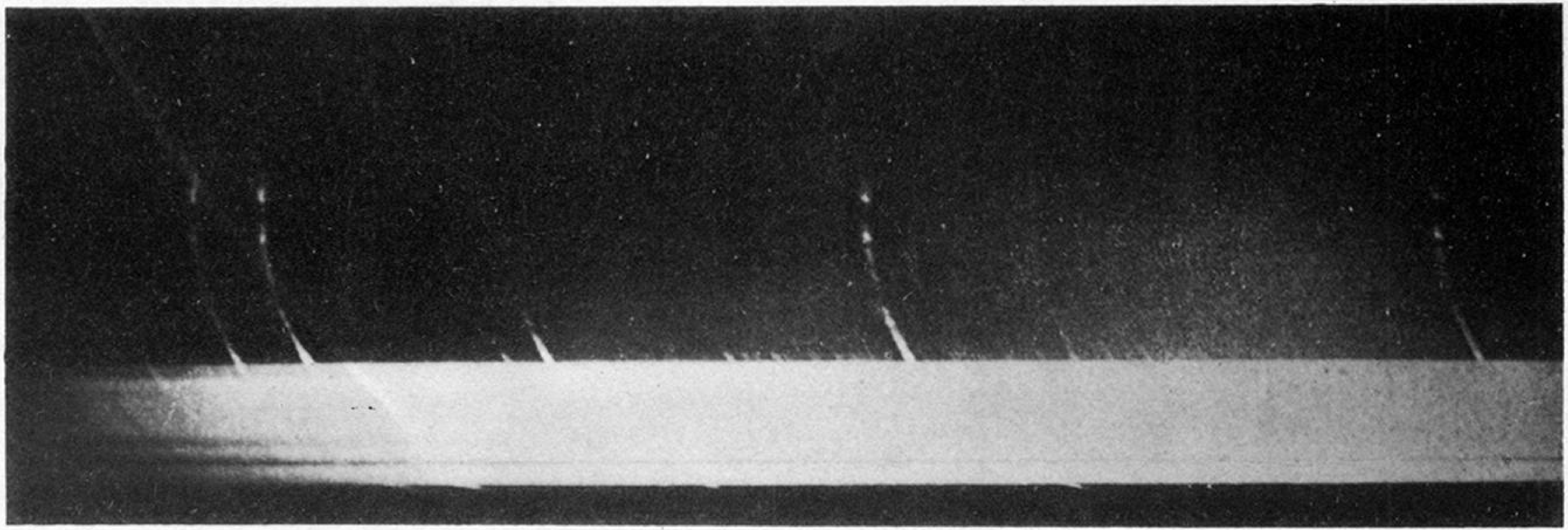
Fig. 16.



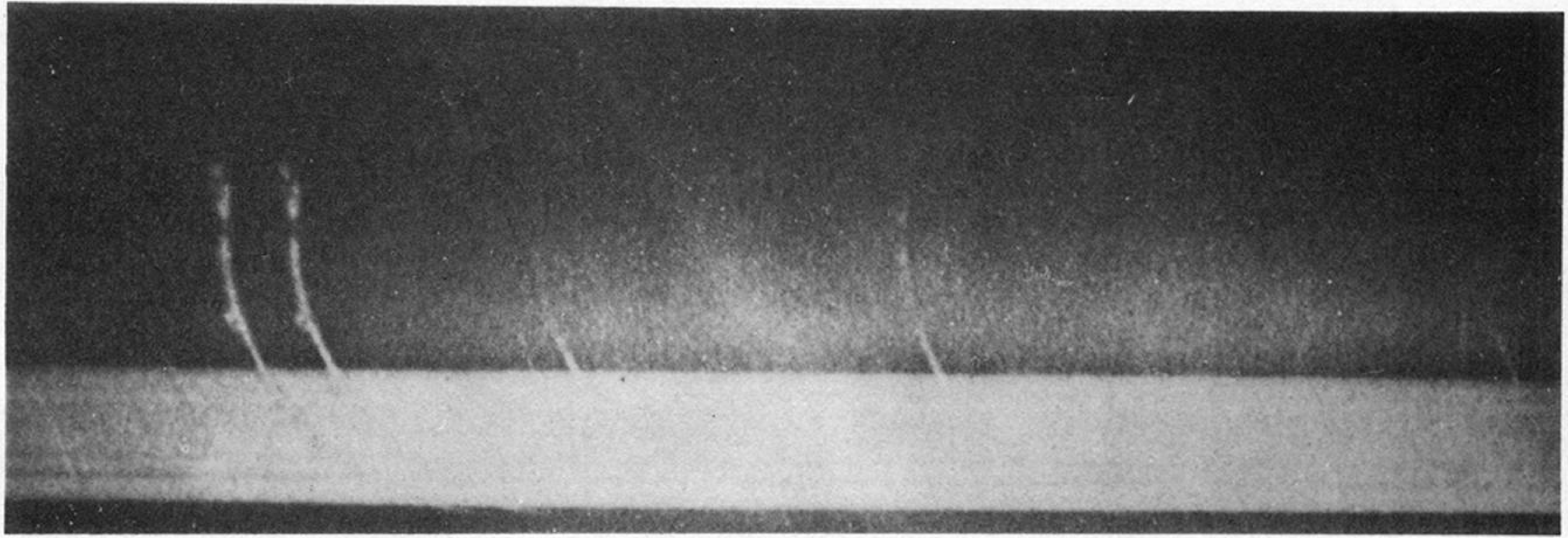
Comparison of the spectrum of the base of the chromosphere with Fraunhofer lines.



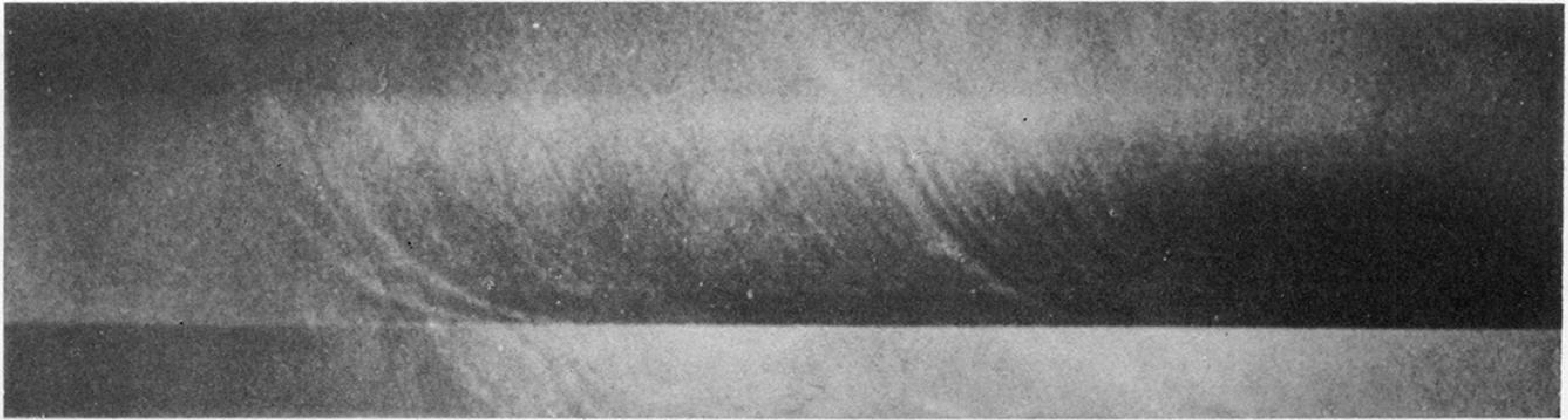
AFRICAN PHOTO No. 22. 3-8 SECONDS AFTER TOTALITY



No. 23. 10 SECONDS AFTER TOTALITY

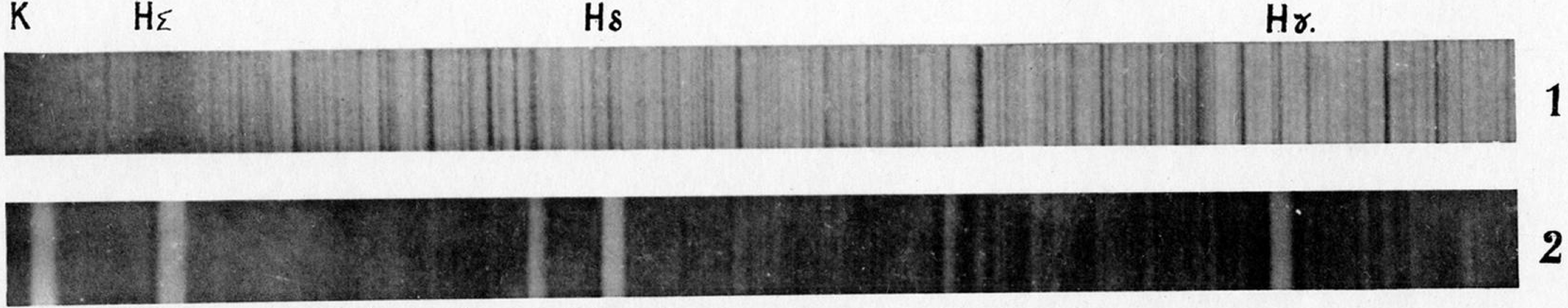


No. 24. 11 SECONDS AFTER TOTALITY



No. 25.   41-49 SECONDS AFTER TOTALITY

Spectrum of Prominence Nº 3. (*a*) 22″—26″ above photosphere; (*b*) 7″—9″, (*c*) 3″·7; compared with spectrum of base of chromosphere (*d*).



The spectrum of the base of the chromosphere (2) compared with the spectrum of Arcturus (1).