XII. *Solar Eclipse of* 1900, *May* 28.—*General Discussion of Spectroscopic Results.*

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[Plates 2, 3.]

In the preliminary report of an expedition to the south limit of totality, in Algeria, I described in detail the methods adopted and the instruments employed in obtaining photographs of the "flash" spectrum in high solar latitudes.*

The present paper deals with the results obtained from a detailed study and measurement of four of the best negatives of the series of sixteen which were secured with the principal instrument, a reflecting prismatic camera.

This instrument was an ordinary reflecting telescope of 188 centims. focus, fitted with two prisms of light flint glass at the upper end of the tube near the position usually occupied by the small mirror of the Newtonian reflector. The prisms had an effective aperture of 8 centims. and angles of 60° and 45° respectively; they were set approximately at minimum deviation for K, and gave a linear dispersion at the focus of the large mirror equal to 93 millims. between F and K.

Description of the Photographs.

The plates were exposed near the time of greatest phase of the eclipse, which was not quite total at my station. The first plate was exposed at 45 seconds before, and the last at 32 seconds after, the computed time of mid-eclipse. Owing to the position of my station, near the extreme limit of the zone of total-eclipse, and just outside that limit, there appears in all the photographs a considerable amount of continuous spectrum due to the uneclipsed photosphere. Notwithstanding this, all the exposures which were made within 15 seconds of mid-eclipse yielded good images of the flash spectrum, and the sky illumination was sufficiently reduced to allow of the fainter

* 'Roy. Soc. Proc.,' vol. 67, p. 370.

spectrum arcs being impressed during quite half a minute at the time of greatest obscuration (see Plate 2).

In all the images the continuous spectrum extends from λ3500 to λ5100, and throughout this long range the focus appears to be almost perfect, a striking testimony to the good qualities of the reflector as compared with a lens.

Some of the stronger arcs show a diffuseness on the violet side, a defect which has been traced to a want of homogeneity in the glass at the base of the 60° prism. In the ultra-violet region this shading becomes scarcely noticeable, and the definition here is very fine; this is no doubt owing to the almost complete absorption of the ultra-violet rays in traversing the thickest part of the prisms.

The four negatives selected for special study, and which are reproduced in Plate 2, are from the exposures numbered 9, 10, 11, and 13.

No. 9 was exposed for 2 seconds, beginning 15 seconds before mid-eclipse. The flash spectrum is impressed in a rather narrow rift in the continuous spectrum, extending from position angle 140° to 148°, and including a region between 70° and 77° south latitude. The bright arcs crossing the rift are exceedingly narrow thread-like lines, well defined throughout the spectrum, and are therefore well adapted for accurate wave-length determinations. Although the arcs are inclined about 30° from the normal to the direction of dispersion, this was found in making the measures to detract but very little from the accuracy of a setting.

In the ultra-violet the Fraunhofer lines are particularly well-defined in this image right up to the end of the plate on the continuous spectrum, but between $H\zeta$ and $H\beta$ they are obliterated by over-exposure.* The stronger dark lines, and many of the weaker ones, are continuous with and run into bright lines in the rift, and in several instances the density of the silver deposit is the same in the bright line as it is in the dark line, giving the impression that the change from dark to bright is entirely one of contrast resulting from the withdrawal of the bright background of continuous spectrum. Some of the more intense lines, such as those of titanium at λλ 3685, 3759, and 3761, do not become dark lines on the continuous spectrum, but, being more intense than the latter, appear bright even upon the bright background.

This may be accounted for by the great altitude to which the titanium vapour extends, not to its being intrinsically brighter than the photosphere at the limb. For the continuous spectrum is produced by what is virtually a slit of extreme fineness, defined by the limbs of the sun and moon, and subtending an angle of less than 1″, whilst the titanium spectrum comes from a stratum, or virtual slit, of 7″ or 8″ in angular width.

No. 10 was exposed also for 2 seconds at about 10 seconds before mid-eclipse. The limb of the moon, advancing eastwards, has covered up the lowest strata of the flash in the position where the lines are so well developed in No. 9. There is, however, a

* In the reproductions the Fraunhofer lines are almost invisible except at the extreme ultra-violet end in No. 13.

good but narrow image of the flash at about position angle 137°, or latitude − 63° to − 66° E.; and on the west side also there is a fine thread of faint continuous spectrum in latitude − 56° W., upon which the flash lines appear as minute dots, like beads on a string. About twelve of these dots may be counted between H and K.

No. 11 spectrum was exposed during 10 seconds near the time of mid-eclipse. Judging by the symmetrical distribution of the bands of continuous spectrum on each side of the central line of the image, the middle of the exposure must have been timed almost at the moment of greatest phase, which appears to have coincided with the computed time of mid-eclipse.

The continuous spectrum in this negative is reduced to nine or ten narrow bands, due to indentations in the moon's limb, and the flash spectrum appears in the form of long arcs crossing the bands and extending over the whole of the south-polar region of the sun. Most of the arcs cover 80° degrees of the limb, extending from latitude − 75° on the east side to latitude − 28° on the west. The sharpest definition is along a band at position angle 212° in latitude − 41° on the west side, and this portion of the image was selected for measures of wave-length and estimates of intensity.

The bright lines on this negative are more strongly impressed, and can be traced further towards the more refrangible end of the spectrum than in any of the other images. Some of the Fraunhofer dark lines can still be traced near the end of the image in the ultra-violet, crossing the narrow strips of continuous spectrum. These lines therefore do not wholly disappear before the last remnants of continuous spectrum vanish, but they become exceedingly faint, and are easily obliterated by over-exposure.

No. 13 spectrum, exposed for 2 seconds about 14 seconds after mid-phase, shows a considerable arc of the photosphere uncovered over the south-west limb, and the negative is somewhat fogged from the increasing sky illumination. There is, however, a good image of the flash spectrum near the middle line of the image in the south-east quadrant. The lines are here very short, the flash layer being exposed in a narrow depression of the moon's limb, but they are well adapted for measurement.

Methods of Measurement.

The photographs numbered 9, 11, and 13 were measured with a micrometer microscope, lent to me for this purpose by Major HILLS, R.E. This instrument has a screw of 1 millim. pitch and about 200 millims. in length. The head of the screw being divided to 100 parts, readings can be made to ·01 millim., and by estimation to ·001 millim.

In practice it was found that ·01 millim. was about the limit of accuracy attainable with the best defined lines. A preliminary set of measures of the sharpest lines over the whole length of spectrum photographed was made, to test the accuracy of the screw over long runs, a duplicate series of measures being made over the same portion of the screw, but with the negative reversed end for end. A comparison of the direct and reversed measures revealed systematic differences amounting to as much as ·02 millim. in a run of 100 millims.

Although this error of run would have very little effect on the resulting wave-lengths, which depend ultimately on short measured distances from known lines, it was considered more satisfactory to measure the photographs in three sections of about 70 millims. each, selecting a portion of the screw which gave consistent results over this range. In order to reduce the accidental errors of setting, and to detect blunders, each section was measured twice, one set of measures with the red end to the right, and the other with the red end to the left.

This method involved some extra labour in combining the measures, and in joining up the three sections into one consistent whole by means of the lines which overlapped between the sections. However, the definition of some of the images is so good that any amount of trouble taken in getting satisfactory measures seemed to be justified.

The relation between wave-length and measured distances at all points in the spectrum was determined approximately by graphical methods, using 42 well-known lines, including lines of hydrogen, calcium, titanium and iron, &c. A large number of the finer lines were then identified with certainty, and in the final reduction the broad over-exposed hydrogen and calcium lines were rejected as standards, and about 65 more suitable lines were selected which are well distributed throughout the spectrum, using in the ultra-violet region lines which I considered thoroughly well identified in the spectra obtained in 1898.*

From the standard lines the position in millimetres of each 50 tenth-metre of wave-length was computed, taking the mean value given by four or five of the nearest standards in each case. A table of differences was then made giving the intermediate values by interpolation and the value in millimetres of one tenth-metre at every 25 units.

The wave-lengths of all the lines, including the standards, were computed from this table, using second differences.

Each of the three spectra measured was reduced independently, using the same standard lines, but computing a separate table for each. A direct comparison of the three sets of measures showed that they were very nearly identical, and one table might have served for all. But there appear small systematic differences, due in part the fact that the measures were made at different distances from the centre of the arcs, and probably in part also to slight irregular contraction of the photographic films in drying.

It was therefore considered more satisfactory to treat each spectrum entirely independently, combining in the end the wave-length values obtained to arrive at the most probable values measured on all three spectra.

* 'Phil. Trans.,' A, vol. 197.

From the accordance between the two sets of measures for each spectrum the accidental errors of the mean positions may be estimated at about ·01 millim. The mean error is less than this for the best defined lines, but greater for the broad or diffuse lines. This error corresponds to an error in wave-length of ·16 tenth-metre at 5000, decreasing to ·07 at 4000, and ·04 at the end of the spectra at 3500.

It does not, of course, follow that the wave-lengths in the tables can be relied on within these limits, except for isolated lines of which the measures are unaffected by any disturbing causes, such as faint companion lines or shadings. But this degree of accuracy seems actually to have been attained in a large proportion of the iron and titanium and other well-identified lines (see Table I., p. 478).

The mean values for the hydrogen lines, given separately in Table II., agree very closely indeed with the computed values. Thus in nineteen lines, in a total of twenty-eight, the differences do not exceed ·04 tenth-metre, and in four lines only the differences reach ·1 tenth-metre, three of these being the lines γ, δ and ϵ, which are difficult to bisect on account of their great width. This result will, perhaps, best indicate the general accuracy of the wave-length work.

No corrections of any kind have been applied to the results, and it may be well to emphasise here the fact that no corrections are needed for apparent displacements due to the different altitudes to which the various gases ascend in the chromosphere. In making the measures, the settings were made at the position of maximum density in the case of the broad over-exposed hydrogen lines, the finer lines being simply bisected without reference to the apparent edge of the moon's limb.

It is probable that the positions of maximum density of the images of the stronger lines correspond to radiations coming from a region within 2″ of the photosphere, whilst in the fainter ultra-violet hydrogen series the radiations are almost confined to the flash spectrum layer, the emission from the upper chromosphere being almost insensible for these lines.

Assuming that all the settings were made on arcs radiated from a region within 2″ of the photosphere, this being the approximate limit to which the reversing layer extends, no appreciable error will be made by bisecting the images; for a difference of 1″ of arc in the positions of the various gases above the moon's limb would make an apparent shift on the plate at 188 centims. focus of ·0091 millim., a quantity about equal to the accidental errors of measurement.

On the other hand, if the settings were made on the inner edge of the arcs, that is, at the apparent limb of the moon, a considerable error would be introduced, depending on the intensities of lines, which spread inwards as well as outwards as a result of irradiation.

It is particularly noticeable that a large number of the arcs of the flash spectrum in these prismatic camera photographs are narrow lines sharply defined on both sides, there is no diffuseness on the outer side, as might be expected were the arcs *true images* of the strata producing them. They are in reality, as I have previously pointed out,* diffraction images more or less enlarged by photographic diffusion, and they appear to be as well adapted for bisection and wave-length determination as are the lines given by a slit-spectroscope.

Exception may, perhaps, be taken in the case of the helium lines and the somewhat remarkable line at 4685·7. These do not increase in intensity towards the photosphere, and it is possible that they are very weak and even absent from the flash layer. A bisection of these arcs may, therefore, represent a point in the chromosphere higher than the flash layer.

No allowance has, however, been made for this, yet the values obtained indicate only a small displacement towards the red end, averaging ·16 tenth-metre for the three lines 4713, 4471, and 4026, when compared with the principal components of the double lines as determined by RUNGE and PASCHEN, and which they are assumed to represent.

But it is noticeable that in these spectra the helium lines become broad and faint in the flash layer, although narrow strong lines outside; the measures are, therefore, somewhat uncertain, and it is possible that they may be partly affected by the less refrangible components of the double lines. In any case they serve to show what a small correction is needed, even for the lines of a substance like helium, which is characteristic of the upper chromosphere rather than the flash layer.

Estimates of Intensity.

On account of the great range of intensity between the weakest and the strongest lines, a scale was adopted ranging from 0 to 100. This is practically equivalent to adopting two orders of intensity, 0 to 10 representing the weak lines, 10 to 100 the strong lines, the latter progressing by fives.

The intensities of all the lines, with the exception of those of hydrogen and H and K, were estimated while making the measures, two independent estimates of each line being obtained from the two sets of measures of each spectrum. The mean of the two estimates is set down for each spectrum in Table I.

The hydrogen and calcium lines were estimated separately. From $H\zeta$ to $H\rho$ they form a nearly uniformly diminishing series, giving a convenient scale of reference with which to compare the strong lines of the flash spectrum.

At the ends of the spectra, where the density of the image falls off considerably, the estimates are of course very rough and uncertain, and throughout the middle portions of the spectra the intensities are not perhaps strictly comparable, except over a limited range of wave-length.

* 'Phil. Trans.,' A, vol. 197, p. 394.

General Discussion of Results.

The identification of the bright lines in these spectra with the dark lines of the Fraunhofer spectrum presents very little difficulty in the case of the strong, or well-defined flash lines, and it appears to be generally true that the more reliable the values of wave-length obtained in photographs of the flash, the more closely do they correspond with ROWLAND'S values of the dark lines. Thus many of the lines measured on small-scale photographs obtained in 1898 show apparent displacements considerably greater than the accuracy of the measures seemed to warrant, and which rendered many of the identifications doubtful. This is particularly the case in the region between 3700 and 3900, where the iron lines especially seemed to be systematically of smaller wave-length than the corresponding dark lines, whilst the hydrogen lines in the same region agreed very closely indeed with their theoretical positions. In the present measures, however, in which the scale of the plates is nearly four times greater, these displacements are not confirmed, and the same lines are found to agree with ROWLAND'S values within ·04 tenth-metre.

As regards the fainter ill-defined lines and groups there is, of course, considerable uncertainty in assigning the particular dark lines of which they are supposed to be the reversals, or which lines in a group of dark lines are reversed in the flash.

It is, however, abundantly clear, from an examination of Table I., that every well-defined bright line of the flash (excluding hydrogen and helium lines and the line at 4685·7) can be assigned to a dark line of ROWLAND'S table of an intensity exceeding 2 of his scale. There are no bright lines of even medium strength which occur in blank spaces of the solar spectrum where the lines are weaker than 0, and only a few of the very weakest lines in the table coincide with solar lines with an intensity less than 2.

As a corollary to this, it may be stated that in general the greater the intensity of a dark line in the solar spectrum, the more probable is its presence as a bright line in any given image of the flash, and in the long range of spectrum covered by the spectra under discussion, λ 3500 to λ 5000, the dark lines of intensities exceeding 7 are all present as bright lines, except in two or three instances where they are obviously obscured by strong hydrogen or calcium lines.

In the tables of flash-spectrum lines published by FROST and by MITCHELL, the same general fact is apparent in the large number of identifications made with prominent Fraunhofer lines. Professor FROST concludes that "at least 60 per cent. (and probably many more) of the stronger dark lines of the solar spectrum are found bright in a stratum not exceeding 1″ in height above the photosphere."*

It will probably be generally admitted, therefore, that the flash spectrum as photographed hitherto is a reversal of the more prominent of the Fraunhofer lines,

* 'Astrophysical Journal,' vol. XII., p. 345.

and does not include lines (other than those of He and H) which are not present in the dark line spectrum.

The most important point remaining open for discussion is the relation of the intensities of the bright lines to those of their dark line equivalents, for on this point turns the question whether the flash spectrum layer is in truth the stratum which by its absorption gives rise to the Fraunhofer spectrum.

In discussing the results of the flash spectra obtained in India in 1898,* I stated certain conclusions leading to the belief that the flash spectrum does, in fact, represent the upper more diffused portion of an absorbing stratum which, taken as a whole, produces the Fraunhofer lines. The conclusions relating to the relative intensities of the lines I now recapitulate in the following three paragraphs :—

(1) The relative intensities of the lines of any one element in the flash spectrum are practically the same as those of the same element in the solar spectrum.

(2) The relative intensities between groups of lines belonging to different elements are widely different in the flash and in the solar spectrum.

(3) The apparent intensity of the radiation from an element in the lower chromosphere is determined by the extent to which that element is diffused above the photosphere, and the real relative intensities between the different elements cannot be judged in photographs of the flash spectrum.

The statements in the second and third paragraphs will now probably be generally admitted, and do not need further discussion. It remains to determine how far the statement given in the first paragraph is borne out by the present results, which cover a somewhat different range of the spectrum, give more accurate values of the wave-lengths, and which give very much more complete and reliable values of the intensities of the lines.

Probably this is the most important conclusion deduced from my former results, and as it is one which is most open to criticism, I propose to deal with it in some detail, and with especial reference to the results obtained by FOWLER and BAXANDALL under Sir NORMAN LOCKYER. These investigators have found that the relative intensities of the lines of an element in the flash approximate to those in the spark spectrum, whilst the intensities of the dark lines closely resemble those in the arc spectrum ; whence they conclude that the flash spectrum layer is not the seat of the Fraunhofer absorption lines.†

In making comparisons of intensity in the bright line and dark line spectra of an element, a serious difficulty is encountered in the probably compound nature of many of the apparently single lines of the flash spectrum. In such cases it is, of course, impossible to assign the true value of intensity to the components; even when the unequal components of an obviously double line are easily distinguished, it is difficult

* 'Phil. Trans.,' A, vol. 197.

† See FOWLER on the Flash Spectrum, 'Observatory,' April, 1902. Also Sir N. LOCKYER and BAXANDALL, 'Monthly Notices, R.A.S.,' vol. LXI., Appendix.

to estimate the intensities correctly, the weaker component being liable to be considerably under-estimated.

Another difficulty occurs when single Fraunhofer lines have a compound origin assigned, such as Fe–Ti, &c., the proportion of intensity of each element in the "make up" of the dark line being unknown. In such cases the relative proportions of intensity in the corresponding flash line may be quite different or even reversed, the predominating element being in general the one which ascends to the greatest elevation in the chromosphere, not necessarily the one which predominates in the dark line.

In these circumstances it is impossible to make anything like a complete or final comparison of intensities. The best that can be done is to select for each element isolated lines which are least open to the suspicion of being made up of more than one line in the flash spectrum, and also lines of supposed single origin as given in ROWLAND's tables.

Unfortunately, there are only three elements which have a sufficient number of lines in their spectra to be treated satisfactorily in this way; they are iron, titanium, and chromium. In the following tables I give the results for these elements, selecting 219 Fe lines of ROWLAND's intensity 3 and upwards, 124 Ti lines of intensity 1 and upwards, and 157 Cr lines of intensity 0 and over.

These are represented in the flash spectra by 93 Fe lines, 39 Ti lines, and 25 Cr lines respectively. The selection of suitable lines was made entirely from ROWLAND's table, and without reference to the flash spectra, so as to avoid bias in the selection.

ROWLAND's intensities of the solar lines are given in the first column of each table, and the number of lines selected between λλ 3500 and 5000 in the second column, the third and fourth columns give respectively the numbers and percentages of the lines which are found as bright lines in the flash spectrum, the fifth column giving the average intensity of these lines.

A glance at the first and last column of each table will show the general relation between the flash intensity and the dark-line intensities for the three elements considered. The numbers indicating intensities for the bright and dark lines are not, of course, directly comparable, since they depend on methods of judging intensity which may differ widely in the two cases. It is a mere coincidence in the case of iron that the numbers representing the stronger lines practically correspond in the first and last columns.

From the columns of percentages the general rule is obvious, that the stronger the dark line of an element, the more probable is its occurrence as a bright line in any given image of the flash spectrum. Thus we find that of the Ti lines none are present in the spectra under discussion corresponding to ROWLAND's intensity 1, and the percentage of dark lines exceeding intensity 1 which are present as bright lines increases with each increase of dark-line intensity up to intensity 4; of the 12 dark lines exceeding intensity 4, all are present in the flash. Similarly with iron, all of the 32 lines exceeding ROWLAND'S intensity 8 are present in the flash and none under his intensity 3.

This general law of correspondence of intensity between bright lines and dark lines is, however, far from being exact in detail even with the selected lines used in these comparisons, and the average intensities of the bright lines are in some instances made up of rather widely diverging units.

This is more particularly the case with the weaker dark lines of each element, which are often of abnormal intensity in the flash. In the case of chromium most of the flash lines corresponding with solar lines of intensity 2 and 3 may be considered abnormally strong, for the average intensities for these lines are greater than the average of the lines corresponding with the solar lines of intensity 4.

The percentage columns show also that many dark lines of medium intensity may be absent in the flash, whilst other weaker lines are present.

It must be remembered that estimates of intensity in the flash spectrum, however carefully made, are liable to considerable errors for several reasons. The great weakening of the spectrum near the ends of the plate materially affects the percentages of the weaker lines as given above, and the low dispersion of the plates compared with those on which ROWLAND'S estimates were based introduces other sources of discrepancy. Moreover, ROWLAND'S table itself is admittedly a "preliminary" table, in which some of the assignments of origin may be erroneous or incomplete, lines having a single origin assigned being really made up of two or more elements.

IRON Lines in Sun and Flash.

Including all isolated lines in ROWLAND'S table assigned to Fe only between λ 3500 and λ 5000, excepting those which are obscured in the flash by strong hydrogen and calcium lines.*

ROWLAND'S intensity in ⊙.	Number of lines in ⊙.	Number of lines in flash.	Percentage of lines in flash.	Average intensity in flash.
Under 3	Very large number	0	0	—
3 and 4	94	12	13	5
5 „ 6	66	26	40	3
7 „ 8	27	23	85	6
9 to 14	13	13	100	8
15 „ 20	14	14	100	17
25 and over	5	5	100	24

* Including three lines ascribed to Fe only by LOCKYER at λλ 4179, 4233, and 4515.

ABNORMAL Fe Lines.

In sun.		In flash.		If enhanced.	Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.		
Lines strong in flash.					
3558·67	8	3558·9	20	?	
3570·27	20	3570·33	30	?	
3634·47	3	3634·48	5	?	
3647·99	12	3647·98	15	?	
3856·52	8	3856·47	15	No	
4179·03	3	4179·1	8	Yes	
4233·33	4	4233·3	10	Yes	
4325·94	8	4325·8	15	No	
4404·93	10	4404·8	20	No	
4515·51	3	4515·6	8	Yes	
4584·02	4	4583·9	25	Yes	
4924·11	5	4924·1	25	Yes	
5018·63	4	5018·5	20	Yes	
Lines weak or absent in flash and exceeding intensity 6 in ⊙.					
3536·71	7	Absent	—	?	Spectrum very weak here.
3651·61	7	3651·85	0	?	
3680·07	9	3680·4 ±	0	?	Hτ interferes at 3679·4.
3684·26	7	3684·29	0	?	Ti line at 3685·3 interferes.
3701·23	8	3701·28	3	?	
3705·71	9	3705·67	5?	No	Flash line confused with strong line at 3706·09.
3850·12	10	3850·26	2	No	
3878·15	8	Absent ?	—	No	This line seems to be present on some images not measured.
4528·80	8	4529·0	1	No	

TITANIUM Lines in Sun and Flash.

Including all lines in ROWLAND's table assigned to Ti only between λ 3500 and λ 5000, excepting those which are obscured in the flash by strong hydrogen lines.

ROWLAND's intensity in ⊙.	Number of lines in ⊙.	Number of lines in flash.	Percentage of lines in flash.	Average intensity in flash.
1	38	0	0	—
2	28	5	18	10*
3	27	9	33	8
4	19	13	68	16
5	7	7	100	21
6 and 7	2	2	100	37
Over 7	3	3	100	55

* The average intensity of the five flash lines is increased by two very abnormal lines at λλ 3505·06 and 3520·40, omitting these the average would be 4.

ABNORMAL Ti Lines.

In sun. Wave-length.	In sun. Intensity.	In flash. Wave-length.	In flash. Intensity.	If enhanced.	Remarks.
Lines strong in flash.					
3505·06	2	3505·1	20	?	
3510·99	5	3511·1	30	?	
3520·40	2	3520·4	20	?	
3535·55	4	3535·75	50	?	Perhaps compounded of Ti and a line at 3535·87, intensity 3 ? origin.
3641·47	4	3641·48	40	?	
4294·20	2	4294·35	12	Yes	
4395·20	3	4395·15	30	Yes	
4417·88	3	4417·7	20–	Yes	
4501·45	5	4501·5	30	Yes	
Lines weak or absent in flash and exceeding intensity 3 in ⊙.					
3653·64	5	3653·67	5	?	
3753·00	4	3652·72	0	No	
3924·67	4	3924·8	0	No	
3948·82	4	3949·11	4	No	
3981·92	4	3981·3 } 3982·2 }	5	No	
3989·91	4	3990·12	2	No	
4171·21	4	Absent	—	No	
4291·11 }	3	Absent	—	No	
·28 }	2				
4306·08	4	4306·0	1	No	
4533·42	4	Absent	—	No	Perhaps obscured by strong Ti line at 4534·14.
4534·95	4	Absent	—	No	
4981·91	4	Absent	—	No	Spectrum very weak here.

CHROMIUM Lines in Sun and Flash.

Including all isolated lines in ROWLAND's table assigned to Cr only.

ROWLAND's intensity in ⊙.	Number of lines in ⊙.	Number of lines in flash.	Percentage of lines in flash.	Average intensity in flash.
0 and 1	109	3	3	0
2	22	4	18	1
3	15	8	46	2
4	3	3	100	1
5	3	2	67	3
6 to 8	3	3	100	13
9 and 10	2	2	100	25

ABNORMAL Cr Lines.

In sun.		In flash.		If enhanced.	Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.		
Lines strong in flash.					
3593·64	9	3593·65	30	?	
4242·54	2	4242·6	1	Yes	
4359·78	3	4358·9 to 4360·2	5?	No	The Cr line is confused with other lines in flash.
4539·95	0	4539·8	0	No	
4541·69	2	4541·6	1	No	
4558·82	3	4558·8	8	Yes	
4588·38	3	4588·0	2	Yes	
4666·39	0	4666·5	5	No	
·66	1				
4708·20	2	4708·1	1	No	
Lines weak or absent in flash intensity exceeding 3 in ⊙.					
4626·36	5	Absent	—	No	Present in FROST'S and MITCHELL'S lists.
4651·46	4	4651·3	2?	No	Spectrum very weak here.
4652·34	5	Absent	—	No	

These sources of error would all tend to produce discordances in the relative intensities between the dark lines of an element and their bright reversals in the flash, and the question arises whether the apparent anomalies which are indicated above are to be ascribed to such imperfections in our knowledge of the spectra, or to fundamental differences such as might be expected were the emission and absorption spectra produced in separate and distinct layers of the sun's atmosphere, and under different conditions of temperature and pressure.

Under the heading "Abnormal lines" I give with each table a list of the lines with intensities in the flash considerably above the average, corresponding with the dark line intensity, and a list also of the exceptionally weak or absent lines.

In these lists the wave-lengths and intensities of the solar lines, from ROWLAND, are entered in the first two columns, followed by the wave-lengths and intensities taken from Table I. in columns 3 and 4. The fifth column indicates whether the line is an "enhanced" line or not, *i.e.*, a line which is relatively brighter in the spark than in the arc spectrum of the element as determined by LOCKYER.

It is at once apparent that many of the abnormally bright flash lines are enhanced lines, whilst none of the abnormally weak lines are enhanced lines. The lists of enhanced lines published by Sir NORMAN LOCKYER do not include the ultra-violet region beyond λ 3800, it is uncertain, therefore, whether the flash lines in this region are enhanced lines or not. If these are omitted, all the titanium lines abnormally strong in the flash, and all the iron lines excepting the three at λλ 3856·5, 4325·9, and 4404·8, are enhanced lines.

If all the enhanced lines in the above-mentioned lists are considered, it is found that all the more strongly enhanced lines of iron and titanium coincide with strong lines in the flash (11 Fe lines and 21 Ti lines). But since many of these lines are of compound origin in the flash, it is not possible to say whether they are all of *abnormal* intensity, *e.g.*, 4351·9, 4549·6, 4556·1, 4629·6, and others. The quartette of enhanced iron lines at 4508·5, 4515·5, 4520·4 and 4522·7 are all abnormally strong in the flash considered as Fe lines only, but according to ROWLAND three of these are of compound origin, one including Ti. However, it seems probable that the abnormal intensity of this group is chiefly due to the fact that the lines are enhanced lines.

There can be little doubt from this inquiry that the enhanced lines *do* play a significant part in the flash spectrum, and the abnormal intensities of these lines are not due to errors in the assignment of origin in ROWLAND'S tables or to over-estimates of intensity in the flash.

Of the abnormally weak lines a considerable number are probably the result of under-estimates due to the close proximity of very strong lines of other elements. There remain a few, however, which cannot be thus explained; among these particular attention may be called to the titanium lines at λλ 3753·00, 3924·67, 4171·21, and 4306·08, all of intensity 4 in the solar spectrum, and the chromium line at λ 4626·36. No satisfactory reason can at present be given for the weakness or absence of these lines in the flash spectrum.

Notwithstanding these instances of disagreement between the intensities of the Fraunhofer lines of an element and their flash spectrum equivalents, the general agreement between the two spectra is so striking that it can scarcely be maintained that there is a fundamental difference in the conditions under which they are produced. The abnormally strong lines in the flash, which in so many cases are also lines which are enhanced in the spark, would, it is true, indicate that some of the radiating gas at all events must be in a condition differing from that in the absorbing layer, and this, it must be acknowledged, is of great interest and importance, particularly in view of the fact pointed out by FOWLER, that under some stellar conditions, *e.g.*, in α Cygni, these particular lines constitute a separate and much simpler spectrum quite free from admixture with the ordinary arc lines.*

But, as I hope to show in what follows, the prominence of these enhanced lines in the flash can be simply explained without abandoning the view that the flash region is really identical with the absorbing layer, and in the great majority of cases the flash lines are true reversals of the dark lines.

In all photographs hitherto obtained at stations near the central line of eclipse, the flash spectrum must represent the more elevated region of the radiating gases, since

* 'Observatory,' June, 1902.

this portion of the layer remains uncovered by the moon for an appreciable time after the sky glare is withdrawn at totality, whilst the lower dense strata immediately in contact with the photosphere are instantaneously occulted.

It might reasonably be assumed, therefore, that the intensities of the bright lines in the lowest strata differ to some extent from those in the spectra photographed, and even more closely approximate to the intensities in the Fraunhofer spectrum.

But the photographs under discussion portray a *grazing* contact, in which the motion of the moon was not across but parallel to the flash layer. These spectra, therefore, should more truly represent the radiation from the entire depth of the layer, at any rate at points near the apex of the bright arcs, and where the layer is sufficiently uncovered, because at such points the very lowest strata would remain visible throughout the time the plate was exposed.*

A careful comparison between the intensities of the lines at points near to and far from the apex, or centre line of the spectra, shows, however, that there are no appreciable differences.

Moreover, the intensities given in Table I., which were estimated at points not far from the apex, and where the continuous spectrum of the photosphere was just beginning to appear, will be found to be in substantial agreement with the results of LOCKYER (1898), FROST (1900), and MITCHELL (1901), all of which were obtained near the central line.

It seems, therefore, that there can be no very striking differences between the spectra of the higher and lower regions of the flash layer as regards the intensities of the lines, unless absorption by the upper regions through which the line of sight passes should neutralise such differences. In particular it may be noted that the enhanced lines seem to predominate throughout the entire region.

If it is assumed that the differences between spark and arc spectra are conditioned by temperature, the spark being the hotter, it would seem at first sight that the flash region must have a higher temperature, and must consequently be distinct from the absorbing layer, since in the latter the intensities of the lines closely approximate to those in the arc. I think it can be shown, however, that the spark and arc conditions may *co-exist* at the same altitude above the photosphere.

It is well known that the outer limit of the chromosphere, as seen in the line of hydrogen, presents a structure of small filaments like blades of grass covering the entire surface, and very unlike the diffused, indefinite limit which a true atmospheric envelope might be expected to present.

According to SECCHI, "at the base of the chromosphere the hydrogen has the shape of small, close filaments which seem to correspond with the granulations of the photosphere." †

* The terms *layer* and *strata* are here used for convenience, but it is not intended to imply that the gases of the chromosphere are in reality stratified.

† 'Popular Astronomy,' S. NEWCOMB, p. 275.

This structure suggests that the chromosphere is in reality a region of innumerable small eruptions of the same nature as the jets of highly luminous gas which are constantly to be seen with the spectroscope in all regions of the sun's limb. It is probable, indeed, that these jets, and the larger eruptive prominences, are in reality only the more pronounced manifestations of a phenomenon occurring on a smaller scale everywhere over the solar surface.

The highly-heated gases composing these eruptions, which may be supposed to originate below the photospheric level, would lose heat as they ascended by adiabatic expansion and by radiation, and at a certain elevation would precipitate the more refractory substances as highly luminous clouds, forming, in fact, the photospheric granules and the columnar filaments observed in sunspots. But the gaseous streams, deprived of their condensable materials, would continue to ascend above the photosphere, finally becoming diffused in the region of the chromosphere. The expanded gases, subsequently subsiding in a relatively cooled condition, would form a strongly absorbing atmosphere settling down uniformly and slowly upon the photosphere and through which the ascending streams would be forced.

If this really represents roughly the actual state of things, it is clear that the temperature conditions represented by the electric spark and by the arc may both exist at the same altitude above the photosphere, the spark condition in the highly-heated ascending gases and the arc condition in the cooler descending gases.

Seen at the sun's limb, as under the conditions of a total eclipse, the more intense spectrum of the ascending gases would be neutralised to a considerable extent by the absorption of the cooler gases in which the jets would be immersed, and through which for immense distances the line of sight must pass. But just those particular rays which are characteristic of the high temperature spectrum would not suffer absorption to nearly the same extent, consequently these rays (the enhanced spark lines) would stand out conspicuously in a spectrum which in its main features would be the emission spectrum of the cooler descending gases, *i.e.*, the reversed Fraunhofer spectrum.

The relatively cool gases would obviously determine the character of the absorption spectrum of the disk, and the only effect of the hotter eruptions, supposing them to be too small to be individually distinguishable in the spectroscope, would be to produce a faint emission line of about the same intensity as the background of continuous spectrum, and tending to diminish the intensity and width of all the dark lines, particularly the enhanced spark lines.

In this way, by assuming the presence of innumerable eruptions of hot gas and cooler but quietly descending absorbing gases, the abnormal intensity of the enhanced lines in the flash can be simply explained without abandoning the view that the flash spectrum is really the reversed Fraunhofer spectrum, and that the entire depth of the flash region, and, indeed, of the chromosphere itself, is effective in producing the absorption lines.

That there really exists a circulation of the solar gases in a radial direction is strikingly shown in the detailed structure of some of the Fraunhofer lines themselves. DESLANDRES has called attention to certain peculiarities in the structure of the lines H and K in the general light of the sun and in particular regions of the solar surface.*

These lines consist of three distinct portions—a broad diffuse absorption shading, a bright rather wide emission line near the centre of the shading, and a narrow absorption line which obliterates all but the edges of the underlying bright line.

DESLANDRES finds that over undisturbed regions of the disk, and at some distance from the limb, the central absorption line is always displaced towards the red with respect to the underlying emission line, producing a dissymmetry in the edges of the latter. This he attributes to a vertical circulation of the calcium vapour, the ascending gas producing the emission line slightly displaced to the violet, whilst the cooler descending gas gives rise to the central absorption line displaced to the red.

According to JEWELL, all the strongly shaded lines exhibit an emission line, which is very nearly obscured by a central strong absorption line usually unsymmetrically placed. Traces of an emission line are also visible at the sides of some of the narrow unshaded lines. The effect of motion of the hot gas he considers, however, to be masked to a certain extent by pressure shift, the displacement of the emission line to the violet by reason of the ascending motion being partly neutralised by an opposite displacement due to pressure.†

Some sort of circulation of the solar gases in a radial direction and all over the surface, such as is demanded by the theory of "convective equilibrium," would seem, therefore, to be established, the ascending gases rising with sufficient velocity to appreciably displace the emission lines when observed on the sun's disk, whilst the more diffused absorbing gases descending with a more uniform motion produce the well-defined dark lines very slightly displaced to the red compared with the same lines from a terrestrial source. Obviously such motion of the gases being in a radial direction will not affect the position or definition of the bright lines of the flash spectrum as seen at the limb during an eclipse.

A difficulty has to be faced, however, when we try to account for the apparent sorting out of the different elements in the chromosphere, which seems to depend in a general way on atomic weight, the lighter elements ascending to greater elevations than the heavier.‡

But an eruption in the ordinary sense due to an explosion would give equal

* 'Comptes Rendus,' August, 1894.

† 'Astrophysical Journal,' vol. III., p. 100, *et seq.*

‡ The exceptional altitudes reached by the elements Ca and Ti do not materially affect this general law, which asserts itself by the absence in the chromosphere of nearly all the elements having atomic weights exceeding that of Zr (91), Ba and La being, perhaps, the only elements with a higher atomic weight that have been identified with tolerable certainty in the flash spectrum.

velocities to the whole mass of mixed gases, and it is difficult to see why these should not be projected to equal altitudes in the chromosphere, yet most of the metals with atomic weights between 20 and 100 stop short at from 1″ to 2″ elevation, whilst the elements H, He, Ca, and Ti ascend to 8″ or 10.″

The same lagging behind of the elements of the lower chromosphere occurs, however, in the so-called "metallic" and great eruptive prominences.* In these the higher parts usually consist solely of H, He, Ca and probably Ti, the other elements only appearing at the base or stem of the prominence, or frequently only in the surrounding chromosphere. In the more violent eruptions, too, the distortions due to motion in the line of sight affect chiefly the hydrogen and calcium lines, the lines of other elements present in such outbursts being usually undisturbed, or but slightly affected, showing that these elements, although apparently mixed up with the hydrogen, do not share in the motion.

Although it may be difficult at present to understand the nature of these great eruptions, it would seem reasonable to suppose that the entire chromosphere consists of miniature eruptive prominences of the same nature as the greater outbursts, the base of the eruptions giving the metallic lines of the flash spectrum and the higher parts the lines of H, He, Ca and Ti only.

This conclusion is strengthened when it is remembered that the strongly enhanced lines of iron at 5317, 5269, 5018, and 4924 so prominent in the flash, are always the first to appear as bright lines in the metallic eruptions, other iron lines, although stronger than the above in the Fraunhofer spectrum, being seldom or never seen reversed. This is doubtless owing to the relatively high temperature of the gases in these eruptions compared with the absorbing gases, and in the lower chromosphere the enhanced lines indicate a similar state of things, the highly-heated ascending jets giving a high temperature emission spectrum more nearly resembling that of the spark than of the arc.

The Flash Spectrum in High Latitudes.

It is of interest to compare the images at different points on the limb to determine whether the flash spectrum is the same in all latitudes. The limited distribution of the metallic prominences, which, in the writer's experience, are only to be found in the latitudes of spot formation, would perhaps lead one to anticipate some modification of the spectrum in high latitudes.

At the date of the eclipse (May 28th, 1900) the sun's south pole was at position angle 164° and very nearly coincident with the limb. Unfortunately, this point, and the region within 10° of it on either side, is occupied by the continuous spectrum

* No spectroscopic distinction can be made between the metallic eruptions and the more quiescent forms of prominence, for the latter, when photographed at an eclipse, exhibit the same metallic lines at their bases as the former.

in all the images obtained before mid-eclipse, and in those obtained after that phase only the stronger lines are impressed, the moon's limb having occulted the stratum very rapidly, notwithstanding that the motion was nearly parallel to it. This would indicate an extreme shallowness of the layer near the pole.

In the mid-eclipse photograph, No. 11, the continuous spectrum being broken up into narrow bands, the flash spectrum arcs can be traced right across the polar region near the more refrangible end of the plate. In the portion of spectrum between F and K the bands coalesce from over-exposure and obscure the bright arcs entirely.

The highest latitudes in which really good images of the flash spectrum occur are $-70°$ to $-77°$ on the east side in No. 9, and $-76°$ on the west side in No. 13; and the lowest latitude is in $-36°$ to $-41°$ on the west side in No. 11. Intermediate between these there are the excellent images in latitude $-56°$ west and $-64°$ east in No. 10. From this material comparisons can be made between the spectra at fairly high latitudes and those at mid-latitudes, and as a check on the results the east and west limbs at about the same latitudes can be compared.

All these images are indicated on Plate 2 by arrows at the ends of the spectra, and the position of the south pole is similarly shown for each spectrum. In Plate 3 a limited portion of the spectrum is shown for the three images which were measured. These are on a scale equal to 4·3 times that of the original negatives, and the curved arcs have been converted into linear spectra by means of a cylindrical lens during the process of enlargement. Great care was taken to avoid the production of spurious lines due to defects in the negatives.

Comparing the two high-latitude spectra shown in the upper and lower figures of Plate 3 with the mid-latitude spectrum placed between them, it is not easy to detect differences which can fairly be ascribed to latitude. It may be noticed that the titanium line at about λ 3900 and the aluminium line at λ 3944 are both relatively weak in the upper spectrum (latitude $-74°$ East) compared with the middle spectrum (latitude $-41°$ West). But in the lower spectrum, from an equally high latitude on the opposite side of the pole, these lines are as strong as in No. 11 spectrum.

There are many other minor differences in relative intensities between the three spectra, as will be apparent on comparing the three columns of intensities given in Table I., but these seem to bear no relation to difference of latitude.

A special effort was made to discover any modification of intensity in the enhanced lines near the pole, and the average intensity of all the more prominent enhanced lines of iron and titanium in Nos. 9 and 13 spectra was compared with the average of these lines in No. 11 spectrum, making due allowance for the greater intensity of No. 11 spectrum, as a whole, compared with the others.

The result is shown in the following table :—

TABLE I.—Eclipse Spectra, May 28, 1900—continued.

Wave-lengths. No. 9. Latitude −74° E.	Wave-lengths. No. 11. Latitude −41° W.	Wave-lengths. No. 13. Latitude −75° W.	Intensities. No. 9.	Intensities. No. 11.	Intensities. No. 13.	Remarks.	Adopted wave-length.	Intensity.	Wave-length in sun (ROWLAND).	Intensity.	Element.
3893·31	3893·17	3893·59	0	0	0	. . . .	3893·35	0	—	—	—
94·24	94·49	—	—	—	—	. . . .	94·36	0	3894·165 94·211	3 8	Fe, Cr, V ? Cr, CO
95·14	—	—	1	—	—	. . . .	—	—	95·119	3	Co
	95·81	95·91	—	10	3	In No. 9 perhaps 2 lines, 3895·1 and 96·5	95·85	10	95·803	7	Fe
96·52	—	—	1	—	—	. . . .	—	—	—	—	—
98·15	98·31	98·09	0	1	0	. . . .	98·18	1	98·151	5	V
99·89	99·88	99·98	1	3	0	Narrow line in 11	99·92	3	99·850	8	Fe
3900·75	3900·65	3900·63	10	25	8	Poor definition in 13	3900·68	25	3900·681	5	*Ti*-Fe
03·17	03·19	03·13	1	7	1	. . . .	03·16	7	03·090	10	Cr, -Fe, Mo
05·62	05·69	05·74	1	5	1	. . . .	05·68	5	05·660	12	Si
—	06·45	06·65	—	3	0	. . . .	06·55	3	06·628	10	Fe
07·24	07·31	—	1	0	—	. . . .	07·27	0	—	—	—
08·48	08·71	—	0	1	—	. . . .	08·60	1	—	—	—
09·95	09·98	—	0	0	—	. . . .	09·97	0	09·802 09·976	4 5	Fe Fe, V
—	11·22	—	—	0	—	. . . .	11·22	0	—	—	—
—	12·37	—	—	1	—	. . . .	12·37	1	—	—	—
13·57	13·55	13·55	10	25	6	. . . .	13·56	25	13·609	5	Ti-
14·52	14·52	14·67	0	1	1	On continuous spectrum only in 11; diffuse in all	14·57	1	14·566	1	?
16·07	16·15	16·17	10	3	2	. . . .	16·10	3	16·079 16·207	1 0	Zr Zr, La
18·53	18·53	18·51	1	1	4	Wide in 13	18·53	1	18·464 18·563	4 4	Fe Fe
20·28	20·31	20·41	0	8	5	Wide in 13	20·33	8	20·410	10	Fe
—	—	21·90	—	—	0	Narrow lines in 13	21·9	0	21·855	4	Ce, Mn-Zr
—	—	22·68	—	—	1		22·7	1	22·560	1N	V
23·13	23·13	23·18	1	8	3	. . . .	23·14	8	23·054	12	Fe
—	—	24·82	—	—	0	. . . .	24·8	0	24·673	4	Ti
26·01	—	26·28	1	—	0	. . . .	26·14	0	26·123	7	Fe-
28·19	28·14	28·08	1	7	5	. . . .	28·14	7	28·075	8	Fe
30·86	30·49	30·41	3	5	5	. . . .	30·58	5	30·450	8	Fe
33·98	33·79	33·94	100	100	100	K	33·90	100	33·825	1000	Ca
38·39	38·26	38·49	2	5	2	. . . .	38·38	5	38·552	4	?
40·29	—	—	0	—	—	. . . .	40·3	0	—	—	—
44·10	44·14	44·14	2	20	5	. . . .	44·13	20	44·160	15	Al
45·22	45·29	45·29	0	0	1	On continuous spectrum only in 11	45·27	0	45·260	3	Fe
47·65	47·81	47·66	0	0	0	Perhaps 2 lines in 13	47·70	0	47·675 47·918	4 2	Fe Ti
49·61	49·14	49·17	1	4	1	. . . .	49·11	4	48·82 49·039 49·199	4 1 1	Ti Ca La
3950·38	3950·38	3950·48	1		2	. . . .	3950·41	6	3950·497	2	Y