XII. *Spectroscopic Observations of the Sun.*—No. II. *By* J. Norman Lockyer. *Communicated by Dr.* Sharpey, *Sec. R.S.*

Received November 19,—Read November 19 and 26, 1868.

Preliminary Remarks.

In my first paper under the above title, kindly communicated by Dr. Sharpey to the Royal Society in 1866*, was contained an account of the determination of the nature of Sun-spots by means of the spectroscope. The paper concluded as follows:—

"May not the spectroscope afford us evidence of the existence of the 'red-flames' which total eclipses have revealed to us in the sun's atmosphere, although they escape all other methods of observation at other times? and if so, may we not learn something from this of the recent outburst of the star in Corona?"

Before the paper was written I had diligently swept round the solar disk in search of evidence of the red flames, but without result. This want of success I attributed to the excessive brilliancy of the spectrum of the circumsolar regions in the field of view of the instrument employed. I found in fact (although I did not discontinue my efforts) that both for these observations and for those on sun-spots more dispersion was necessary; in one case to weaken the atmospheric light, in the other to widen the spectrum.

I therefore represented my requirements to the Government-Grant Committee, and was at once supplied with funds to procure a spectroscope of the requisite dispersive power.

The construction of this instrument was commenced in the beginning of 1867 by Mr. Cooke, on a plan which had been arranged between us, but unfortunately it was never finished. Mr. Cooke's health was then already failing, and at last, at the end of the year, he begged me to consider the order cancelled. Under these circumstances, at the beginning of the present year I sought the assistance of Mr. Browning; but the construction was further delayed, partly on account of an illness which necessitated my absence from England. At last the instrument, which reflects great credit on Mr. Browning's skill, arrived on the 16th of October, 1868, not quite complete, but in a condition which enabled me to commence work.

I mention these facts, first to account for my apparent inaction, and secondly in order that the coincidence in time of my results with those obtained by the observers of the recent eclipse may not be misinterpreted†.

* Proceedings of the Royal Society, vol. xv. p. 256.

† October 11, 1869.—It is important that I should be allowed further to emphasize this remark, for M. Faye, who was unaware of the date on which my new Spectroscope was received, has stated (Comptes Rendus, t. lxvii. (1868), p. 840), "L'insuccès des tentatives premières de M. Norman Lockyer (il est aisé de s'en rendre compte

I began my work with the new instrument by continuing my search after the prominences. I found that the circumsolar light was now so greatly reduced that, although the lines were faintly seen on a dimly coloured background, the background itself was apparently dark enough to render a bright line distinctly visible. My first attempts, however, with the new instrument, not yet in adjustment, were as unsuccessful as those made with the smaller one; and it was not till the 20th of October that, after sweeping for about an hour round the limb and arriving at the vertex of the image, near the south pole of the sun, I saw a bright line flash into the field.

My eye was so fatigued at the time that I at first doubted its evidence, although, unconsciously, I exclaimed "at last!" The line, however, remained—an exquisitely coloured line absolutely coincident with the line C of the solar spectrum, and, as I saw it, a prolongation of that line. Leaving the telescope to be driven by the clock, I quitted the observatory to fetch my wife to endorse my observation.

Detail of the Observations.

October 20.—Having settled that the new line was absolutely coincident with C, I commenced to search for more lines. This I found very difficult, as the instrument requires several movements and adjustments for the various parts of the spectrum, and the rate of the driving-clock was not properly adjusted for the sun's motion; the prominence was therefore lost at times; moreover the observations were impeded by clouds.

I commenced the search for lines from C to A. B was first brought into the field with the newly discovered line at C. There were no new lines visible. I then made an excursion to A with no result, and returned to C to assure myself that the prominence was still on the slit.

I then worked from the line at C towards D. A little beyond D, the lines of which are widely separated in my instrument, I detected another single and less vivid line, by estimation 8° or 9° of KIRCHHOFF'S scale more refrangible than the more refrangible of the strongest D lines. I could detect no line corresponding to it in the solar spectrum, but the definition was not good.

b was next tried, the excursion now being made from the new line near D. There was no line at *b*, though the new D line was still visible when I returned to it.

In the same manner, after many interruptions from clouds, I tried F; here I found

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aujourd'hui) me paraît tenir à ce que ce savant, dans l'impossibilité où il était alors de prévoir de quelles raies lumineuses se composerait le spectre des protubérances supposées gazeuses, ne savait sur quelles particularités délicates du spectre si compliqué des régions circumsolaires il devait porter son attention. *Cela est si vrai, que c'est seulement quand il a su, par les observateurs français et anglais de l'éclipse, la nature détaillée du spectre des protubérances*, qu'il a réussi à trouver en Angleterre les traces de ce spectre dans celui des régions voisines du bord du soleil."

I think that the illustrious French astronomer, who has otherwise done me such ample justice, will not object to my pointing out this slight inaccuracy, due entirely to the fact that the first communication of my discovery was incomplete in its statement of the circumstances which attended it. The bright lines as seen in my instrument are so obvious and brilliant that a child could not overlook them.—J. N. L., October 10, 1869.

another line. As at first caught it was very long; and by moving the telescope very slightly backwards and forwards in right ascension, in one direction the line shortened and brightened, and was visible on the solar spectrum for some distance, in another direction it became disconnected with the spectrum altogether. I was hence able to determine roughly the shape and dimensions of the prominence.

It was extremely difficult to fix the exact position of the line at F, although I had had no difficulty or even cause for hesitation about the others. It seemed at times to lie athwart the F line in the faint spectrum, although at first it had appeared more refrangible, especially when it was visible on the solar spectrum itself.

October 22.—Two days afterwards I had another opportunity of observing the prominence spectrum, and of endorsing everything I had observed on the former occasion. With regard to the F line, I traced the bright line parallel to the dark line and outside it (*i. e.* more refrangible) further than I did on the 20th, but once or twice I caught it inside F on the sun.

I found that a narrow slit was best for D and F, as there are bright bands in the solar spectrum at those points. The lines were always visible with the usual width of slit. C was bright enough to allow the slit to be widened.

On this day, as on the 20th, my attention was strongly drawn to certain bright regions in the spectrum.

October 27.—On this date the prominence first observed was no longer on the limb, I had to search therefore for a new one; I found one on the eastern equatorial limb. The method of observation previously adopted was changed, and a mixed spectrum of the sun's limb and prominence was obtained. The two spectra were in fact superposed.

In the case of the line at C, the result was to absolutely eclipse the dark line in the spectrum, and to replace it by a vividly bright band (Plate XXXVII. fig. 5). The behaviour of the F line was still a puzzle to me. In the spectrum of the light proceeding from the exact limb of the sun the bright line was seen more refrangible than F, but in the spectrum of the prominence at some distance above the sun the black line F was eclipsed (Plate XXXVII. fig. 6). This experiment, which I repeated several times, seemed in a measure to explain what I had before observed; and under this date I entered in my note-book: "It appears that away from the sun's surface the substance gives out less refrangible light than it does when apparently at the surface."

November 5.—The next observations were made on this date under superb atmospheric conditions, and after an important alteration had been made in the instrument, enabling me to make the several adjustments with the utmost nicety.

After the adjustments to the sun's limb had been made, I at once saw what I imagined to be the indication of a small prominence, and swept for a development of it, thinking that the portion observed might be one of the loops or lower levels which generally separate the higher peaks. Having swept for some distance on both sides the region on which the telescope was clamped in the first instance, and finding everywhere the same uniformity of height, it at once struck me that I was in presence of something

new, and that possibly what I was seeing might indicate a solar envelope. I rapidly, therefore, tried several other parts of the limb to test the idea. It was soon established. *In every solar latitude both the* C *and* F *bright lines were seen extending above the solar spectrum.* The spectrum near D was so bright that I was compelled to refrain from examining it, but I caught the line near D once.

The thickness of this envelope I found to be sensibly uniform, except in the regions where it was heaped up with prominences.

The spectrum of the envelope cleared up all the difficulties connected with the F line. Perfect definition and adjustment now enabled me to see that the base of the bright line widens out as the solar spectrum is approached, and that whereas the line, away from the sun, corresponds, in the case of an ordinary prominence, in refrangibility and thickness to the FRAUNHOFER line F, close to the sun it widens out, so as to overlap the F line on both its sides to an extent about equal to its thickness, so that it is three times broader, or perhaps more, on and close to the limb.

In the spectrum of a prominence in which violent action was going on the line thickened out in the same manner at some distance above the limb (Plate XXXVII. fig. 4). There was no thickening observed in the C line at the base, or in the case of the phenomenon just referred to.

I obtained on this day the outlines and dimensions of two prominences.

November 6.—The observations made on the preceding day were confirmed, and one of the prominences reobserved. I also suspected a new line a little less refrangible than C.

November 8.—The line suspected on the 6th was seen several times to-day. It came out beautifully with very varying brilliancy and even colour, to judge by appearance and impressions. It is very much thinner than the bright line C, and seems only to flash out where great action is going on, which slightly thickens the C line at its base. It is so near the C line that when both are shining brilliantly the line looks a double one, like D in a spectroscope of moderate dispersive power.

To-day for the first time I got definite evidence of what I had suspected on several occasions with regard to different parts of the spectrum. A bright line was observed in the solar spectrum itself, a little less refrangible than the line C.

On the Spectrum of the Prominences.

The existence of three lines in the spectrum of the prominences and their approximate positions were determined and communicated to the Royal Society on the 20th of October. See Plate XXXVII. figs. 1, 2, 3.

The coincidence of one of the lines with the solar line C was at once determined.

The coincidence of another line with F at a certain distance from the sun's surface was finally determined on the 5th of November, when the fact of the widening out of the lines towards the sun was discovered.

The exact position of the line near D is shown in Plate XXXVII. fig. 2, in which it

is laid down from the mean of three careful micrometrical measurements made under far from good atmospheric conditions on the 15th of November. In KIRCHHOFF'S map the new line falls in a region where no line was measured by him. I may also add that, by the kindness of Mr. GASSIOT, I have been enabled to inspect the very elaborate maps of the spectrum constructed at Kew Observatory. The measures above given make the new line fall between two lines of almost inconceivable faintness; in Mr. GASSIOT'S map, indeed, there are none but such lines for some distance on either side of the region in which the new one falls.

On the 8th of November the existence of another line was definitely established; its position in the spectrum is slightly less refrangible than FRAUNHOFER'S C.

Unlike the other lines, which are seen in all prominences, this line is only visible at times, being rendered so apparently by the presence of certain conditions which are not permanent. Intense action going on in a prominence will sometimes render this line visible; I am not, however, prepared to say that this is always the case. The line when visible is much more variable than the others; at times it is the mere ghost of a line, at others it rivals the C line in brilliancy.

Of the three lines C is generally more brilliant than F; but I should add that it is difficult to determine the relative brilliancy of the lines because they are never seen together in the field of view of my instrument. The relative brilliancy of the line near D I am not sure about, because its situation in the brightest portion of the spectrum not only renders comparison difficult, but renders any conclusion which may be formed little worthy of confidence. My observations so far (November 16th) induce me to ascribe great variability, not only to the absolute, but to the relative, brightness of the lines. One instance is of the utmost importance. On the 5th of November, in sweeping round the sun with the F line in the field of view, I came across a prominence in which action of the intensest kind was evidently going on; the light and colour of the F line were most vivid, the luminosity of the line was greater than that of any part of the solar spectrum then visible in the field (Plate XXXVII. fig. 4). The action was not general, but limited to certain points, as if the prominences were built up of clouds, and the action was intensest at their centres; where the light was most vivid the spectrum widened out to almost the same extent as at the base*. The C line exhibited all the variations of brightness, but they were unaccompanied by any very decided widening of the line. The spectrum was too bright to observe the effect on the line near D.

On the Dimensions and Forms of the Prominences.

The prominence first observed on October 20th on the (true) southern limb of the sun was an exceedingly fine one; its shape, as determined by sweeping the slit over it, was as represented in Plate XXXVII. fig. 7; its apparent height was about 3′. I did not stop to measure it more accurately. This prominence was not so visible on the next day of observation (the 22nd), as the sun's rotation had carried it on to the disk.

* This might have been an effect of irr^{a}diation, but I can scarcely think so.

On the 5th of November I obtained the outline of two brilliant prominences, one near the southern, the other near the northern limb of the sun. The extreme (measured) apparent height of one was 35,000 miles, of the other somewhat less; the former I estimated to extend along the sun for about 200,000 miles. The shape of the southern prominence had changed considerably by the next day, the bright peak being quite gone; at the same time the length of the main portion had extended as if the peak had been absorbed into it (Plate XXXVII. figs. 8 & 9).

The prominences therefore change from day to day; at present I have not measured any more rapid change, but these observations are of so delicate a nature that it is easy to imagine rapid changes to be going on in any prominence of decided outline; for an error in the adjustment of the instrument with regard to the meridian or latitude, the least variation in the rate of the driving-clock, or any oscillation of the telescope-tube or the spectroscope, brings the slit on another part of the outline of the prominence, and under these circumstances the length of the line is perpetually varying.

It must be borne in mind that the dimensions of the prominences cannot be determined absolutely, as we do not know whether they are actually on the sun's limb at the time of measurement. Measurement can only fix a minimum.

On the Continuous Solar Envelopes.

The continuity of this envelope, which I propose to name the CHROMOSPHERE, a name suggested by Dr. SHARPEY, was spectroscopically established on the 5th of November, and an account of the observations was transmitted to the Royal Society on the same day.

By careful estimations made on the 6th of November (which are estimations only, for I had not yet mounted a wire-micrometer on the spectroscope-telescope), its general thickness was determined to be about 5000 miles; the level of its upper surface was not absolutely uniform in all latitudes, but it was very nearly so. I could detect no difference in the general level as between the equatorial and solar regions of the sun.

It would appear that the light by which its existence is revealed proceeds from the same substance or substances of which the prominences are composed; and I hold the prominences to be merely the heaping together of the new envelope in some localities.

Under proper instrumental conditions the spectrum of this envelope can always be seen whenever the sun is shining. The spectrum consists of a line coincident with FRAUNHOFER'S C, another more refrangible than D, and another coincident in the main with F. I say coincident in the main, because when the spectrum of the envelope is viewed so that it appears to rest on the solar spectrum, the line at F takes the form of an arrow-head (Plate XXXVII. fig. 3), the shaft of the arrow being represented by the black line F in the solar spectrum itself. This results from a thickening out of the line as it approaches the sun. At the outer surface of the envelope the refrangibility of the light is the same as that of the line F; but, as the sun's surface is approached, the line widens gradually into a band overlapping F by more than its own thickness on either side, and more on the more refrangible side than on the other. The black line F

also loses its thickness as it approaches the boundary of the spectrum. The amount of widening at the base is subject to variation.

In the spectrum of the chromosphere this widening at the base is not generally observed either in the line at C or in that near D.

None of the lines stop sharply; they all fade out as the limit of the envelope is approached.

On certain Bright Regions in the Solar Spectrum.

From the commencement of my observations with the new instrument my attention has been drawn to certain bright regions in the ordinary spectrum; but it was not till the 8th of November, 1868, that I succeeded in observing a definite bright band extending for a certain distance on the sun near the limb.

I should state that I have observed this behaviour in the F band on either side of FRAUNHOFER'S dark line F, and in the C line, when the prominence, as I have imagined, has extended from the limb over the earth's side of the sun.

The position of the bright band observed on the 8th of November is near C, but slightly less refrangible, not far from the place in the scale occupied by the last discovered red line, the position of which as yet has not been micrometrically determined.

Other regions to which my attention has been particularly drawn from the first, although up to the present time I have obtained no results, lie, one between the *b* lines, another between *b* and F, another less refrangible than B, one near D, and another near G.

It is quite possible that these bright regions, the light of which is variable, may be due to faculæ; this conclusion is strengthened by the fact that diligent sweeping within the limb has not revealed the bright lines of the chromosphere spectrum. If this be so, the faculæ are not the prominences, although they may be possibly connected with them.

On the nature of the Chromosphere and Prominences.

It has already been concluded by M. JANSSEN, from the coincidence of two of the bright lines with C and F, that the prominences are composed of hydrogen.

So far as our present knowledge goes, however, this does not dispose of the other two bright lines, the positions of which have been determined by myself: I allude to the lines near D and near C.

At the present moment I am engaged on a series of experiments on gaseous spectra, which I hope will afford additional information on these points; in the interim, on the assumption that the chromosphere and prominences are wholly, or in part, composed of hydrogen, several considerations which appear to me of great importance may be touched upon.

These considerations are based upon the experiments of MM. PLÜCKER and HITTORF* on the one hand, and of Professor FRANKLAND on the other†. In MM. PLÜCKER and HITTORF'S paper, entitled "On the Spectra of Ignited Gases and Vapours, with especial regard to the different Spectra of the same elementary gaseous substance," these investi-

* Philosophical Transactions, vol. clv. (1865) Part I. pp. 1–29. † Proc. Roy. Ins. vol. v. p. 419.

gators point out the effect of temperature on the different spectra, the temperature of the discharge of RUHMKORFF'S induction-coil being increased by increasing the power of the inducing current, or, preferably, by diminishing the duration of the induced one, by means of the Leyden jar.

Among the important results obtained in the case of nitrogen were the following. With increase of temperature the light passes through the following colours:—

Golden,
Bluish violet,
White,

and at an extreme temperature the lines expand, approaching thus to a continuous spectrum.

We now come to hydrogen. When a GEISSLER'S tube filled with extremely rarefied hydrogen is used, the spectrum produced by a spark of low temperature consists of three lines of the same width as the slit—one red, another bluish green, another violet*; these are respectively termed $H\alpha$, $H\beta$, and $H\gamma$ by MM. PLÜCKER and HITTORF. The places of these lines in the solar spectrum are at C, at F, and one at some distance from G towards F.

I quote the following results of increase of temperature from the memoir under notice.

"Hydrogen shows in the most striking way the expansion of its spectral lines, and their gradual transformation into a continuous spectrum. When the direct discharge of RUHMKORFF'S large induction-coil is sent even through the old spectrum-tubes enclosing hydrogen, the formerly obtained spectrum is essentially altered. By increasing the power of the coil, the violet line $H\gamma$ first expands; while it continues to expand, the expansion of the bluish-green line $H\beta$ becomes visible. Let the aperture of the slit be regulated so that the double sodium-line will separate into two single lines nearly touching one another. Then, the angular breadth of $H\beta$ becoming two or three minutes, the breadth of $H\gamma$ is about double. The expansion takes place as well towards the less as towards the more refracted part of the spectrum. $H\alpha$ remains almost unchanged after $H\gamma$ has passed into an undetermined large violet band, and $H\beta$ extended its decreasing light on its two sides. On employing the Leyden jar, and giving to the gas in our new tubes a tension of about 60 millims., the spectrum is already transformed into a continuous one, with a red line at one of its extremities. At a tension of 360 millims. the continuous spectrum is highly increased in intensity, while the red line $H\alpha$, expanded into a band, scarcely rises from it. If the electric spark passes through hydrogen at the ordinary tension, the ignited gas on its way always gives the spectrum of the three expanded lines.

"Even in the old spectral tubes enclosing highly rarefied hydrogen, the ground, from which the three characteristic lines rise, did not appear always of the same darkness; in some instances new bright lines appeared, *especially in the neighbourhood of the sodium-*

* I am aware that ÅNGSTRÖM has discovered another line, but it is not necessary here to consider it.

line. In resuming the subject, we pointed out the existence of a new hydrogen-spectrum, corresponding to a lower temperature, but having no resemblance at all to the spectra of the first order of nitrogen, sulphur, &c. In this spectrum, of a peculiar character, if fully developed, we observe a great number of well-defined bright lines, almost too numerous to count and represent by an engraving, but brilliant enough to be examined with a magnifying-power of 72, after the light has passed through four prisms.

"On sending the direct discharge of RUHMKORFF'S coil through a tube of glass from one-fourth to one-eighth of an inch in diameter, provided with electrodes of platinum or of aluminium, enclosing hydrogen at a tension of 5 to 10 millims., a luminous thread of light of a bluish-white colour was seen passing along the axis of the tube, without touching the glass. When analyzed by the prism, it gave a faint spectrum of the above-mentioned numerous bright lines, especially within the red and the yellow. Among these lines neither Hα nor Hγ were seen; Hβ only appeared, but less bright than many other lines. By interposing the Leyden jar and gradually increasing its charge, all the lines became brighter, Hβ surpassing all other lines in brilliancy; Hα appeared beautifully, Hγ fainter. Hence we conclude that the numerous bright lines belong neither to the vaporized metal of the electrodes, nor to the decomposed interior surface of the glass, but solely to the hydrogen, constituting a new spectrum of it. This spectrum may be seen simultaneously with the three characteristic lines Hα, Hβ, Hγ; but at an increased temperature, when these lines begin to expand, it entirely disappears."

MM. PLÜCKER and HITTORF also determined the action of the discharge of a small induction-coil through a tube enclosing hydrogen which was gradually rarefied to the highest tenuity to be reached by a GEISSLER'S exhauster; they found that, as the exhaustion proceeded, the red colour of the gas gradually faded into an "undetermined violet," and that Hα disappeared, while Hβ, though fainter, remained well defined.

With hydrogen gas in GEISSLER'S tubes, then, the following facts are established:—

I. With a certain degree of rarefaction and temperature, we obtain three characteristic lines, Hα, Hβ, and Hγ.

II. By increasing the temperature, we expand Hγ first towards both ends of the spectrum, then Hβ, Hα remaining almost unchanged after Hγ has passed into an undetermined large violet band.

III. By increasing the tenuity, Hα disappears first, Hβ remaining well defined, and moreover the colour of the ignited gas changes to the eye.

IV. Under certain conditions, which are not stated in the memoir, new lines appear in the spectrum, especially in the neighbourhood of the sodium-line.

Assuming that hydrogen gas is present in the chromosphere and prominences, we have the following facts to place side by side with those just stated:—

I. In place of the three lines we have but Hα and Hβ.

II. Hβ is in process of expansion, the expansion increasing as the sun is approached, and Hγ is so far expanded that it no longer exists as a line; most careful observations

repeated several times have failed to detect it. Were it a broad band having the same total amount of light, it would be invisible in the spectroscope; it has probably therefore reached this stage.

III. The prominences have been observed of various colours (this fact is not here stated merely with reference to the observation recorded in III. *ante*).

IV. *There is a line in the yellow*, most probably proceeding from the substance which gives off the light at C and F, as the length of this line, as far as the later observations with the more correctly adjusted instrument go, is the same as that of those in C and F.

I am aware that the conditions as to density cannot for one moment be held to be the same in the two cases; but as at present (so far as I know) we have no similar experiments ranging over greatly varying densities, I have thought it desirable to bring these striking facts forward at once. We are justified in thinking that the density of the chromosphere, always assuming that it is composed wholly or in part of hydrogen, cannot be very great; if it were, the spectrum would most probably be continuous; for Professor FRANKLAND has shown, in the lecture before alluded to, that hydrogen burning in oxygen under a pressure of ten atmospheres gives out a spectrum, bright, and perfectly continuous from red to violet.

It is possible that experiments in which both density and temperature are varied may enable us to match accurately the spectrum of the chromosphere, and thereby determine both the temperature and pressure at the surface of the sun.

The bright lines which have been observed in several stars, especially in the remarkable one in Corona, the outburst of which was spectroscopically watched by Mr. HUGGINS in 1866, shows us that under certain conditions of constitution a chromosphere may be a part of the regular star-economy, and be liable to changes more or less great, and effected with more or less rapidity. The continuous observation of the sun's chromosphere may therefore lead to a knowledge of many important facts.

It is remarkable that in the outburst in the star in Corona, two of the lines of the chromosphere were coincident with C and F, and that two other lines were visible. If, therefore, either or both of these lines be due to hydrogen, we must regard that star, leaving the density of the envelope out of consideration, as being of lower temperature than our sun.

The position of the prominences in all parts of the sun's limb has generally been held to be sufficient evidence that they are not connected with spots. They may, however, still result from some common cause. It may be noted that the eclipse which was photographed by Mr. DE LA RUE in Spain happened near the time of maximum sun-spots, and that nearly the whole limb of the sun was covered with prominences. My observations since 1866 have been carried on at the minimum sun-spot period, and the prominences observed during the eclipse this year were few in number, and covered but a small part of the sun's limb.

Received November 26, 1868.

Additional Note on the Chromosphere.

Since my last communication to the Royal Society I have received, through the kindness of Admiral MANNERS, the following extract of a note from Father SECCHI, in which, although the existence of the new continuous envelope is not announced, important corroboration of its existence is contained. Father SECCHI says:—

"Rome, 15 Nov. 1868.

"I have been able to verify the observations of Mr. LOCKYER on the sun, but I find that, even where the lines do not become brilliant, their blackness vanishes by a partial inversion. I have found also some luminous lines which become exceedingly brilliant near the edge of the sun. One is near the ray D, and the other in contact almost with the line B on the side of C.

"*I find that all around the full limb of the sun the inversion takes place.* If the slit is perpendicular to the edge the inversion is a very short part, so  , of 10″ or 15″, but if the slit is parallel to the edge then the inversion is complete. It is a very beautiful fact. It is perhaps one that will modify our ideas on the origin of these lines."

I have italicized the most important part of the letter.

Since the 20th of the present month, in consequence of a conversation on that day with Mr. DE LA RUE, I have gone over my observations of the sun's limb with great care, and have also reexamined Mr. DE LA RUE's photographs with a view to ascertain the evidence which they give of the continuity of the envelope. The result strongly confirms my former views. It is true that the photographs do not show a continuous chromosphere of anything like uniform thickness; but that arises from the fact that the only part of the sun's limb where the envelope was visible at all during totality happened to be covered by irregular prominences, which were probably very abundant at the time. In fact, owing to the relative sizes of the sun and moon during the eclipse of 1860, and the direction of the moon's motion, the top and bottom of the sun's limb, as shown in plate 15 of Mr. DE LA RUE's memoir, were considerably within the moon's limb during the totality; only small portions of the sun's limb on the preceding and the following sides were uncovered, and there the chromosphere is seen to be almost continuous, though, as I have said, very irregular. The absolute want of continuity in the photographs, which, as far as I recollect, is not observable in Mr. DE LA RUE's hand drawing, is not a final argument against its real spectroscopic continuity. On the 24th of November 1868, when I had an opportunity of observing the sun, I employed the whole time in examining into the absolute continuity of the chromosphere; I was enabled, until interrupted by clouds, to examine continuously and carefully about 300 degrees of the sun's contour, and during the time I did not for one moment lose sight of the chromosphere spectrum. It is very gratifying to find that photographs taken many

years ago by so excellent an observer as Mr. DE LA RUE should be found to bear independent testimony to the accuracy of the conclusion which I have arrived at, by an entirely different line of research.

Received April 9, 1869.

Historical Notice of the growth of our knowledge of the Chromosphere.

When I was first enabled, by means of the spectroscope, to determine that the prominences are merely heapings up of an envelope which gave everywhere the spectrum of hydrogen (at pressures which Dr. FRANKLAND and myself have since approximately determined) and is continuous round the sun, or at all events continuous in the same sense that the photosphere is continuous, I was not aware that I had been anticipated in any part of the discovery.

I have since found, however, that the continuity of the envelope, apart from its nature and place in the solar economy, has been suspected for many years, although it had never been demonstrated, as it easily might have been, by eclipse observations at properly chosen stations, and although it has been very variously interpreted.

I think it desirable, now that the spectroscope has determined the existence and nature of such an envelope, that, in justice to myself and to those who have gone over the same ground before me, a brief historical notice of the progress of our knowledge on this point should be given.

It is easy now to divide the phenomena observed in the many eclipses between 1706 and 1842 into two classes:

I. Observations of the prominences properly so called;

II. Observations of the chromosphere;

and all the observations of both these classes, accumulated during the eclipses which happened up to and including the year 1842, have been discussed by two eminent astronomical authorities,—I refer to ARAGO and Professor GRANT, to both of whom, long even before the eclipse of 1851, it was perfectly obvious that the prominences were solar and not lunar phenomena.

ARAGO* considered the prominences to be merely clouds floating in the sun's atmosphere—an atmosphere rendered evident to us by the Corona, and to these clouds he ascribed the spots without a nucleus; to the Corona also he attributed the darkening of the limb. He says:—

"Il faut admettre une enveloppe extérieure qui diminue (éteint) moins la lumière qui vient du centre que les rayons qui viennent sur le long trajet du bord à l'œil. Cette enveloppe extérieure forme la couronne blanchâtre dans les éclipses totales du soleil."

It is not easy to reconcile *all* ARAGO'S statements as to the nature of this atmosphere or envelope; but I shall return shortly to a later enunciation of them by himself, merely

* Annuaire du Bureau des Longitudes, 1846. MSS. quoted by HUMBOLDT, Cosmos, SABINE'S Translation, vol. iv. Notes, p. cii.

remarking here that there is nothing said about the "clouds" forming a continuous envelope round the sun.

Professor GRANT*, who went over the same ground as ARAGO, and had ARAGO's results before him, was led to consider before the eclipse of 1851 that "The observations of solar eclipses would seem to indicate that above the luminiferous envelope there exists a STRATUM of nebulous matter which is visible only by means of reflected light. Various interesting questions present themselves for solution in connexion with the admitted existence of such a STRATUM. In the first place, does this THIRD ENVELOPE exercise an influence in the production of any of the other phenomena which have been disclosed by observations on the physical constitution of the sun?"

Then, referring to Sir J. HERSCHEL's hypothesis of convection currents throwing up the then imagined non-luminous envelope below the photosphere, through the photosphere, he adds:—

"This view of the subject, while it carries with it considerable probability, obviates the necessity of introducing into the theory of the physical constitution of the sun the idea of a third envelope independent of the two others."

We next come to the eclipse of 1851, which was observed by Professor SWAN, among others, who contributed to the Royal Society of Edinburgh three valuable memoirs on the eclipse with special reference to the red prominences. Assuming that they existed in the solar atmosphere, and agreeing with the prescient remarks of Sir J. HERSCHEL, that they must be "cloudy masses of the most excessive tenuity," he remarks†:—

"Obviously the simplest view that can be taken of this phenomenon, is to regard the red fringe and the red prominences as of the same nature; and all the observations will then confirm the idea that the matter composing those objects *is distributed all round the sun*. It therefore seems probable that when we are furnished with observations of a tangential phase of the eclipse from stations on the north side of the moon's shadow, it will be found that a sierra appeared towards the sun's north point, of which the detached prominences seen in that region, by observers situated near the middle of the moon's shadow, were only the highest peaks. . . . . Since, then, it has been shown to be highly probable that the matter composing the red prominences is distributed with little interruption all round the sun, we may conceive the luminous strata of the solar atmosphere to be surmounted by an envelope of clouds of which the higher portions are visible beyond the moon's limb, at the central phase of a total eclipse, and which then constitute the red prominences. If [he continues, throwing out the suggestion previously made by GRANT] it be thought that the hypothesis of two envelopes of cloud, one above and another below the luminous strata of the sun's atmosphere, introduces too great complication, we may avoid the objection by supposing that the envelope which occasions the penumbræ around the spots penetrates the luminous stratum, and exists, although in greatly different degrees of density, both above and below it.

* History of Physical Astronomy, p. 400.

† Transactions of the Royal Society of Edinburgh, vol. xx. part iii. pp. 462, 463, 464.

"If, then, we conceive that a stratum of cloudy matter surrounds the sun, of which the red prominences are the higher portions, the serrated appearance of the long range of prominences, seen by Mr. DAWES and Mr. HIND, sufficiently indicates that its general surface is exceedingly uneven, presenting the appearance of being covered with numerous eminences or ridges. But these irregularities are small when compared with the large hook-shaped prominence, and its companion the detached cloud, which were seen by most of the observers of the eclipse. . . . . .
Now, as the spots have been supposed to arise from upward currents causing apertures in the sun's luminous atmosphere, I conceive the higher red prominences, or those which remain visible at the middle of the total phase of a central eclipse, may in like manner be formed by the same, or similar, currents in the sun's atmosphere, breaking through the envelope of cloud that surrounds him, bending back the edges of the apertures they have formed, and sometimes carrying up detached masses of cloud, such as that which was seen at the late eclipse. We may, however, suppose the envelope of cloud to be sometimes simply raised, without being broken through; and in that state it may form the conical prominences which were observed at the late eclipse.

"Since the prominences reflect, they must also absorb light; and thus the hypothesis which has been proposed regarding them *assumes the presence of an envelope of cloud surrounding the sun's luminous atmosphere, capable of absorbing part of his light and subject to occasional interruptions of its continuity.*"

Mr. SWAN thus formally sums up his most important addition to our knowledge of the solar envelopes, agreeing with ARAGO that the Corona is also a solar appendage. We have now four envelopes.

I. The dark cloud below the photosphere. [The cloudy stratum of HERSCHEL.]
II. The photosphere itself.
III. The envelope of cloud so often referred to.
IV. The sun's atmosphere surrounding all, in which the other envelopes may be supposed to float.

LITTROW, who observed the same eclipse, after describing some of the observations, goes on to say:—

"Tout cela me fortifie dans l'opinion conçue déjà par mon observation seule, que ce bord rouge forme une couche environnant toute la photosphère du soleil, et gonflée çà et là en protubérances"*.

ARAGO in his 'Astronomie'† defends his first view, and criticises Mr. SWAN'S hypothesis. He remarks:—

"Tout s'explique dans l'hypothèse de nuages flottants dans l'atmosphère diaphane qui entoure le soleil.

"J'avais cherché de rendre compte des protubérances lumineuses en les assimilant à des nuages flottants dans l'atmosphère diaphane dont je supposais la photosphère

* Astr. Nachrichten, t. xxxiv. p. 31, and Comptes Rendus, Feb. 22, 1869.
† Ed. 1856, t. iii. p. 623.

entourée. M. SWAN ayant sans doute remarqué dans ma notice cette phrase 'L'éclipse de 1842 nous a mis sur la trace d'un troisième enveloppe située au-dessus de la photosphère et formée de nuages obscurs ou faiblement lumineux,' accumule à la fin de son mémoire citations sur citations, pour prouver que nonobstant ce que cette phrase paraît de renfermer de positif, je n'ai pas eu la pensée qu'il existât au-dessus de la photosphère une couche continue de nuages. JE RECONNAIS LOYALEMENT QUE L'IDÉE DE LA COUCHE CONTINUE APPARTIENT EN PROPRE À M. SWAN."

The next criticism we find brings in the Corona in a way we shall see it again brought forward subsequently.

"La limite extérieure *de la première couronne* lumineuse indiquerait, dans l'hypothèse de M. SWAN, la région qu'occupe la couche continue de nuages dont il croit avoir besoin pour expliquer tous les phenomènes des éclipses totales. Il faudrait donc supposer que, lorsque la couronne est unique, cette couche de nuages s'est abaissée jusqu'à être presque en contact avec la photosphère solaire. C'est alors qu'apparaîtraient les longs arcs courbés, colorés et fortement dentelés, qui ont été signalés par les observateurs comme étant visibles quelques instants après le commencement de l'éclipse totale, et quelques instants avant la fin. Mais admettant pour un moment que ces grands mouvements oscillatoires en hauteur de la couche nuageuse existent, pourquoi cette couche se présenterait-elle comme une ligne circulaire sans couleur lorsqu'elle serait à une grande hauteur, et descendrait-elle irisée et très-irrégulière dans son contour lorsqu'elle se rapprocherait du soleil. Suivant M. SWAN, les protubérances sont des portions de son atmosphère continue, soulevées du-dessus du niveau général par le courant ascendant. Mais comment n'a-t-il pas remarqué qu'en 1842 ces protubérances existaient tout notablement au-dessous de la ligne circulaire qui dessinait les limites de la couronne la plus brillante sur la couronne extérieure?

"Je persiste donc à soutenir simplement que la troisième atmosphère solaire que M. SWAN veut bien admettre avec moi est gazeuse et qu'il y flottent seulement des nuages."

This strong criticism would seem to have had great weight, and I believe that much of the strange modern overlooking of the continuous envelope is to be ascribed to it, to say nothing of the invariable (so far as I know) descriptions of the solar atmosphere to be found in our text-books, on which recent ideas and theories have been based.

We next come to the eclipse of 1851, which was observed in the Brazils. The Brazilian Commission, of which M. LIAIS was a member, sent in a report to the Paris Academy of Sciences, which was reported on by M. FAYE, who commenced his report by thus defining the Corona and prominences*.

"La couronne lumineuse ne serait autre chose que l'indice sensible d'une troisième enveloppe du soleil, d'une atmosphère extérieure. . . . *Les protubérances seraient les nuages de cette troisième atmosphère.*"

I have not been able to obtain the Commissioner's report; but M. LIAIS, in a separate work†, states distinctly (I.) that there is a continuous envelope overlying the photosphere,

* Comptes Rendus, t. xlviii. p. 163.

† L'espace céleste et la nature tropicale.

(II.) that it is not the Corona, (III.) that it is the locus of the general absorption of the photospheric light, and (IV.) that its height is about 3″·3—an immense step in advance, as we now know, on the ideas of Arago. At the same time M. Liais was convinced that the Corona was in reality a solar appendage.

The famous Spanish eclipse of 1860 is next on the list. Mr. De La Rue's admirable photographs have made us all familiar with the solar appendages then visible. Specially to be noticed in them are the points where the limbs of the sun and moon were nearly in contact both at the commencement and at the end of the totality.

In discussing the results of this eclipse, both M. Le Verrier and Father Secchi found themselves compelled to use the word "envelope" to explain all the phenomena observed.

M. Le Verrier*, after a preliminary discussion of the results of this eclipse, remarked, "Faut il croire que la surface entière de l'astre en (nuages rouges) est parsemée jusqu'à une faible hauteur comme elle est semée de facules, et que les nuages roses en sont des émanations commes les taches qui apparaissent sur la disque de l'astre."

And then, after a more complete discussion, he endorses the idea of the complete continuity of the envelope, and makes it at the same time not only the only solar atmosphere, but the origin of spots!!

After referring to Herschel's hypothesis, and remarking "à cette constitution si complexe on eût dû ajouter une troisième enveloppe formée de l'ensemble des nuages roses," he goes on, "or je crains que la plupart de ces enveloppes ne sont de pures fictions; que le soleil ne soit simplement un corps lumineux, en raison de sa haute température, et recouvert par une couche continue de la matière rose dont on connaît aujourd'hui l'existence. L'astre, ainsi privé d'un corps central, liquide ou solide, recouvert d'un atmosphère rentre dans la loi commune de la constitution des corps célestes. . . . . Il paraît clair qu'ils (les protubérances roses) émanent accidentellement d'une couche de matière qui recouvre toute la surface du soleil jusqu'à une hauteur de 8 à 10 secondes. . . "

M. Le Verrier then proceeds to show, as we have seen M. Swan and M. Liais do many years before, that the darkening of the limb is due to this envelope, and then adds, "D'un autre côté il resulte de l'observation des nuages solaires que la matière de l'atmosphère s'accumule quelquefois en quantités plus considérables sur certains points, et comme la lumière de la partie correspondante du soleil peut se trouver plus ou moins éteinte, on arrive à une explication naturelle de l'existence des taches!"

We see, then, that the French results of the eclipse of 1860 entirely endorsed Mr. Swan's assertion of the continuity of the cloudy envelope, although the hypothesis put forward to explain the envelope was completely discordant with observation then and is much more so now.

Father Secchi's idea will be rendered evident by the following extract from his report contained in the memoirs of the Observatory of the Collegio Romano†:—

"La seconda conseguenza, non meno importante è, che questa materia riveste tutta la

* Report quoted in Comptes Rendus, February 8, 1869, page 316.

† New Series, 1860–62, vol. ii. No. 5, p. 43.

superficie solare come un generale inviluppo transparente. Infatti il loro numero prodigioso, e il loro estendersi per archi continuati di molti gradi, ci mostra che è irragionevole supporle, particolarità locali ed eccezionali sulla superficie solare, come sono le macchie, nè possono dirsi eruzioni vulcaniche di pochi punti: al contrario il vederle spuntare congiunte in lunghe catene tanto al principio che al fine della totalità, ci persuade che negli altri punti della circonferenza si rendono visibili solo le cime maggiori e più elevati, restando le minori e più basse coperte dal corpo lunare."

Although these modern results would seem to have settled the question as far as it was possible to settle it by ordinary observations on the central line of totality, I cannot find that the idea of the continuity of the envelope was generally accepted in England or in France.

In 1861 we find M. FAYE* calling upon observers of the eclipse that was to happen on the last day of that year to examine "si cette auréole (la partie de cette couronne la plus voisine du soleil) présente ou non le renversement du spectre solaire, c'est à dire si les raies obscures de FRAUNHOFER seront remplacées dans ce spectre par des raies brillantes." There is not one word about the "couche rose" of M. LE VERRIER!

After this in England we find General SABINE, Dr. BALFOUR STEWART, and Professor CHALLIS independently arriving at the conclusion that the red flames are *solar auroræ*—a theory which I think plainly indicates that the idea that they formed part of a continuous envelope was not in their minds. Mr. BALFOUR STEWART, in a Lecture at the Royal Institution†, remarked:—

"In support of this hypothesis it may be remarked that, during the late total eclipse in Spain, Mr. DE LA RUE, by means of the Kew photoheliograph, proved that these red flames belong to the sun, and that they extended in one case to the distance of 70,000 miles beyond his photosphere. But, considering the gravity of the sun, we are naturally unwilling to suppose that there can be any considerable amount of atmosphere at such a distance from his surface; and we are therefore induced to seek for an explanation of these red flames amongst those phenomena which require the smallest possible amount of atmosphere for their manifestation. Now the experiments of Mr. GASSIOT, and the observed height of the terrestrial aurora alike convince us that this meteor will answer our requirements best. And besides this, the curved appearance of these red flames, and their high actinic power in virtue of which one of them, not visible to the eye, was photographed by Mr. DE LA RUE, are bonds of union between these and terrestrial auroræ."

Although Mr. DE LA RUE in his Memoir refers to the prominences being scattered widely over the sun's disk, it was not till December 1867 that the real meaning of the photographs in this particular was grasped. Mr. STONEY, in a paper communicated to the Royal Astronomical Society in that month, in which he refers to his hypothesis that the sun has an enormous atmosphere, which in eclipses projects far beyond the disk of

* Comptes Rendus, vol. lii. p. 679.

† Proceedings of the Royal Institution, vol. iv. p. 60.

the moon, in which atmosphere the vapours which give rise to the selective absorption of the photospheric light are situated at various heights according to their vapour-density, writes as follows:—

"Directly outside the photosphere there lies a stratum of the sun's atmosphere which is still hotter than the photosphere, and on the outer boundary of this hot region there appears to be a shell of excessively faint cloud, part of which is seen in Mr. De La Rue's photographs of the eclipse of 1860. It probably extends the whole way round the sun. It is therefore very desirable that this faint shell, which seems to lie at a distance of 8″ or 10″ from the edge of the sun's disk, should be observed, both from a central station and from stations close to the northern and southern limits of totality, so as to ascertain whether we have reason to presume it is continuous round the disk"*.

Broadly, then, up to the spectroscopic determination of its continuity and real nature, the story of the chromosphere is as follows:—

1842. Arago refers it to clouds at the base of the Corona, and regards these clouds as the origin of non-nucleated spots, the dimming of the limb being due to the Corona.

1842. Grant acknowledges the continuity of the envelope, ascribes its brilliancy to reflected light, and thinks it may be due to the "cloudy stratum" being driven by convection-currents through the photosphere.

1851. Swan terms it a new envelope of the sun, states that it shines by reflected light, and ascribes to it the dimming of the limb.

1851. Littrow describes it as a continuous thin envelope.

1858. Liais describes it as a continuous envelope, and gives its thickness as 3″·3.

1860. Le Verrier describes it as the unique atmosphere of a solid sun and the origin of all spots.

1860. Secchi acknowledges it as a third envelope.

1867. Stoney considers it as a stratum of cloud at a distance of 8″ or 10″ from the photosphere.

Description of the Plates.

PLATE XXXVII.

Figs. 1, 2, and 3 show the position of the lines observed on October 20, 1868, and their usual form, *i. e.* the line F is broad at the base and gradually tapers upwards, while C, and the line near D (with no corresponding absorption-line ordinarily visible) do not, as a rule, present this peculiarity with the instrument employed.

Fig. 4 shows the appearance of the F line observed on the 5th of November 1868.

Figs. 5 and 6 show the appearances of the C and F lines observed with a tangential slit;

* Monthly Notices of the Royal Astronomical Society, vol. xxviii. p. 19.

in the case of F the bright line observed was sometimes on one side of the absorption-line, and sometimes put it out altogether (October 27).

Figs. 7, 8, and 9 are outlines of the prominences observed on the 20th of October, 5th and 6th of November 1868.

Added October 10, 1869.

PLATE XXXVIII.

The spectroscope of large dispersive power, by means of which the work I have described in the former part of this paper has been done, is attached to a clock-work driven refractor of $6\frac{1}{4}$ inches aperture and $98\frac{1}{2}$ inches focal length, the definition of which is very fine, and worthy of the reputation of its makers, Messrs. Cooke and Sons, York.

Fig. 1 will give a general idea of the spectroscope and of its attachment to the large equatoreal. In this figure are shown the eye-end of the telescope with finder and clamping and adjusting rods, and an internal tube which I have found it convenient to insert into the ordinary one to allow of the adjustment of the spectroscope to the direct solar image, and the variously enlarged images, without disturbing the spectroscope itself on its supports.

This internal tube carries the ordinary eyepiece-end on which the prismatic steel rods which support the train of prisms, collimator, and telescope are fixed and provided with means of rotation.

Fig. 1 also shows the arrangement of the instrument when the direct image is viewed. The eyepiece is taken out, and the image is allowed to fall on the slit-screen outside the telescope. A short collimator collects the light which then passes through the seven prisms (of 45°) of dense flint glass, of which the specific gravity, refractive index, and dispersive power, as determined by Mr. Browning, are as follows:—

Specific gravity	3·91
Refractive index	1·665
Dispersive power	0·0752

Ordinarily the seven prisms are alone used, but when more dispersion is wanted I have found it very convenient to fix an extra prism of 60°, as shown in the figure; this makes the instrument for some part of the spectrum a direct vision one; and I have further increased the dispersion by partly filling the small telescope with direct vision prisms.

The adjustment of the spectroscope to the telescope allows of the slit being brought either tangentially or radially on any part of the sun's limb.

Fig. 2 shows a slit I have designed for comparing various portions of the solar surface with each other. The slit, for purposes of description, may be imagined to be divided into three portions. The central portion admits direct light from some part of the sun;

the upper and lower portions admit light from two other parts of the sun reflected on the slit by means of combinations of prisms.

The slit used in ordinary investigation is similar to that usually employed.

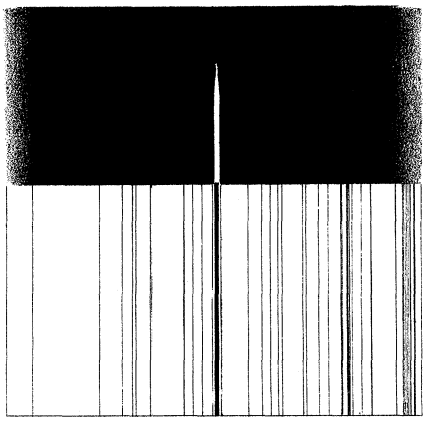
The train of prisms, the collimator, micrometer, and observing telescope are shown in fig. 3 on a larger scale. The prisms are fixed to a plate which it is possible to rotate slightly on its axis, and this, after the more obvious precautions have been taken, constitutes one of the most important adjustments.

The collimator is furnished not only with the usual focusing-screw, but with additional rackwork, which permits of the slit being placed in the image, the colour of which is coincident with the arc under examination. It is only by paying infinite attention to this point that any good results can be obtained; and when this is done, and the atmosphere is pure and calm, the interval between each of the higher cloud-domes on the sun shows an approach to the spot-spectrum, and the spectrum is a mass of horizontal lines. It is rare, however, that the atmosphere is steady enough to show this effect in its greatest perfection.

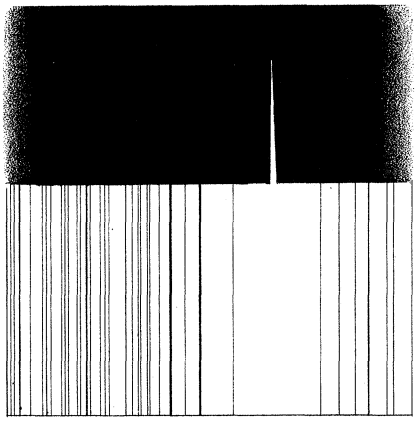
The principal point about the micrometer-arrangement is, that the micrometer-head is read by a little telescope, the eye-end of which is immediately above that of the observing telescope; this saves much time, as the position of the observer is not disturbed when readings are necessary. I have also found it convenient to supplement this arrangement by an ordinary eyepiece-micrometer for differential measures of small range.

I cannot allow myself to conclude this short description without testifying to the great perfection of the optical finish of the new spectroscope, which enables me to obtain a solar spectrum of the utmost purity. My thanks are due to Mr. BROWNING for coming to my aid as he did, and employing his well-known skill in the construction of an instrument at once so unique, portable, and powerful—a task accomplished at last with results most satisfactory to myself and creditable to him.

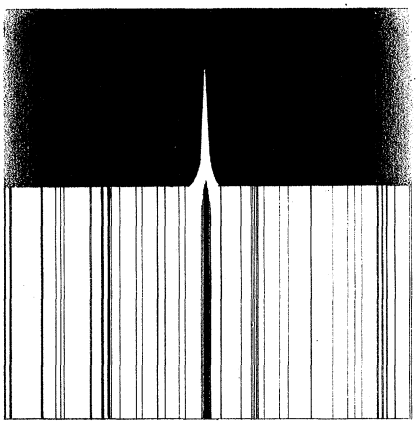
1
C



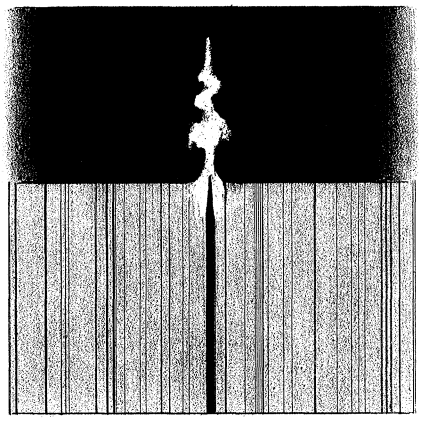
2.
D



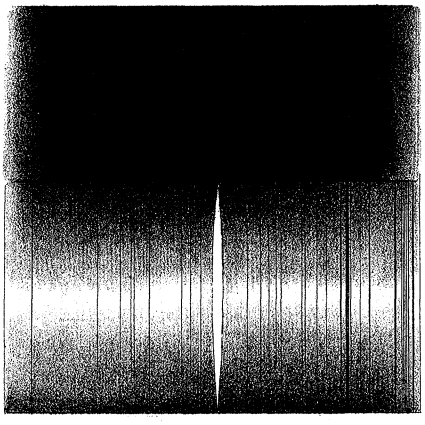
3
F



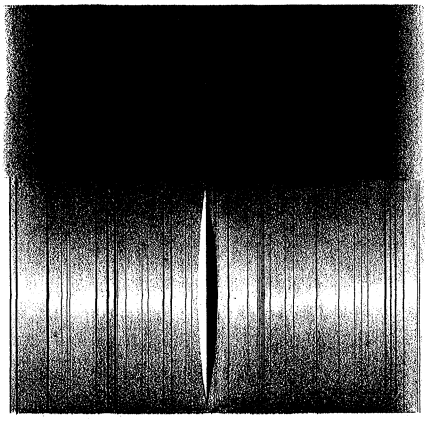
4
F



5.
C.



6.
F



7.

8.

9.

J.N. Lockyer del. W.H. Wesley lith.

W. West imp.

Fig. 2.

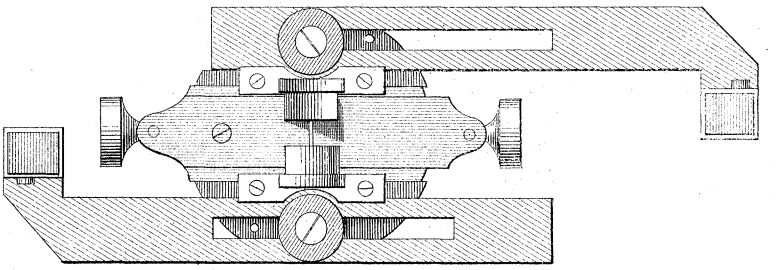


Fig. 3.

Fig. 1.

W. H. Wesley del. et lith.