

red corpuscle of all vertebrata is, in its natural state, structureless. When living, no distinction of parts can be recognized; and the existence of a nucleus in the red corpuscles of ovipara is due to changes after death, or removal from the vessels.

I cannot conclude this paper without acknowledging the great help I have received in this investigation from Mr. Howard Marsh, Demonstrator of Microscopical Anatomy at St. Bartholomew's Hospital.

V. "Spectroscopic Observations of the Sun.—No. III." By J. NORMAN LOCKYER, F.R.A.S. Communicated by Dr. FRANKLAND, F.R.S. Received March 4, 1869.

Since my second paper under the above title was communicated to the Royal Society, the weather has been unfavourable to observatory work to an almost unprecedented degree; and, as a consequence, the number of observations I have been enabled to make during the last four months is very much smaller than I had hoped it would be.

Fortunately, however, the time has not been wholly lost in consequence of the weather; for, by the kindness of Dr. Frankland, I have been able in the interim to familiarize myself at the Royal College of Chemistry with the spectra of gases and vapours under previously untried conditions, and, in addition to the results already communicated to the Royal Society by Dr. Frankland and myself, the experience I have gained at the College of Chemistry has guided me greatly in my observations at the telescope.

In my former paper it was stated that a diligent search after the known third line of hydrogen in the spectrum of the chromosphere had not met with success. When, however, Dr. Frankland and myself had determined that the pressure in the chromosphere even was small, and that the widening out of the hydrogen lines was due in the main, if not entirely, to pressure, I determined to seek for it again under better atmospheric conditions; and I succeeded after some failures. The position of this third line is at 2796 of Kirchhoff's scale. It is generally excessively faint, and much more care is required to see it than is necessary in the case of the other lines; the least haze in the sky puts it out altogether.

Hence, then, with the exception of the bright yellow line, the observed spectra of the prominences and of the chromosphere correspond exactly with the spectrum of hydrogen under different conditions of pressure—a fact not only important in itself, but as pointing to what may be hoped for in the future.

With regard to the yellow line which Dr. Frankland and myself have stated may possibly be due to the radiation of a great thickness of hydrogen, it became a matter of importance to determine whether, like the red and green lines (C & F), it could be seen extending on to the limb. I have not observed this: it has always in my instrument appeared as a very fine sharp line resting absolutely on the solar spectrum, and never encroaching on it.

Dr. Frankland and myself have pointed out that, although the chromosphere and the prominences give out the spectrum of hydrogen, it does not follow that they are composed merely of that substance : supposing others to be mixed up with hydrogen, we might presume that they would be indicated by their selective absorption near the sun's limb. In this case the spectrum of the limb would contain additional Fraunhofer lines. I have pursued this investigation to some extent, with, at present, negative results ; but I find that special instrumental appliances are necessary to settle the question, and these are now being constructed.

If we assume, as already suggested by Dr. Frankland and myself, that no other extensive atmosphere besides the chromosphere overlies the photosphere, the darkening of the limb being due to the general absorption of the chromosphere, it will follow :—

- I. That an additional selective absorption near the limb is extremely probable.
- II. That the hydrogen Fraunhofer lines indicating the absorption of the outer shell of the chromosphere will vary somewhat in thickness : this I find to be the case to a certain extent.
- III. That it is not probable that the prominences will be visible on the sun's disk.

In connexion with the probable chromospheric darkening of the limb, an observation of a spot on February 20th is of importance. The spot observed was near the limb, and the absorption was much greater than anything I had seen before ; so great, in fact, was the *general* absorption, that the several lines could only be distinguished with difficulty, except in the very brightest region. I ascribe this to the greater length of the absorbing medium in the spot itself in the line of sight, when the spot is observed near the limb, than when it is observed in the centre of the disk—another indication of the great general absorbing power of a comparatively thin layer, on rays passing through it obliquely.

I now come to the selective absorption in a spot. I have commenced a map of the spot-spectrum, which, however, will require some time to complete. In the interim, I may state that the result of my work up to the present time in this direction has been to add magnesium and barium to the material (sodium) to which I referred in my paper in 1866, No. I. of the present series ; and I no longer regard a spot simply as a cavity, but as a place in which principally the vapours of sodium, barium, and magnesium (owing to a downrush) occupy a lower position than they do ordinarily in the photosphere.

I do not make this assertion merely on the strength of the lines observed to be thickest in the spot-spectrum, but also upon the following observations on the chromosphere made on the 21st and 28th ultimo.

On both these days the brilliancy of the F line taught me that something unusual was going on ; so I swept along the spectrum to see if any materials were being injected into the chromosphere.

On the 21st I caught a trace of magnesium ; but it was late in the day, and I was compelled to cease observing by houses hiding the sun.

On the 28th I was more fortunate. If anything, the evidences of intense action were stronger than on the 21st, and after one glance at the F line I turned at once to the magnesium lines. I saw them appearing short and faint at the base of the chromosphere. My work on the spots led me to imagine that I should find sodium-vapour associated with the magnesium ; and on turning from *b* to D I found this to be the case. I afterwards reversed barium in the same way. The spectrum of the chromosphere seemed to be full of lines, and I do not think the three substances I have named accounted for all of them. The observation was one of excessive delicacy, as the lines were short and *very thin*. The prominence was a small one, about twice the usual height of the chromosphere ; but the hydrogen lines towered high above those due to the newly injected materials. The lines of magnesium extended perhaps one-sixth of the height of the F line, barium a little less, and sodium least of all.

We have, then, the following facts :—

- I. The lines of sodium, magnesium, and barium, when observed in a spot, are thicker than their usual Fraunhofer lines.
- II. The lines of sodium, magnesium, and barium, when observed in the chromosphere, are thinner than their usual Fraunhofer lines.

A series of experiments bearing upon these observations is now in progress at the College of Chemistry, and will form the subject of a communication from Dr. Frankland and myself. I may at once, however, remark that we have here additional evidence of a fact I asserted in 1865 on telescopic evidence—the fact, namely, that a spot is the seat of a downrush, a downrush to a region, as we now know, where the selective absorption of the upper strata is different from what it would be (and, indeed, is elsewhere) at a higher level.

Messrs. De La Rue, Stewart, and Loewy, who brought forward the theory of a downrush about the same time as my observations were made in 1865, at once suggested as one advantage of this explanation that all the gradations of darkness, from the faculae to the central umbra, are thus supposed to be due to the same cause, namely, the presence to a greater or less extent of a relatively cooler absorbing atmosphere. This I think is now spectroscopically established ; we have, in fact, two causes for the darkening of a spot :—

- I. The general absorption of the chromosphere, thicker here than elsewhere, as the spot is a cavity.
- II. The greater selective absorption of the lower sodium, barium, magnesium stratum, the surface of its last layer being below the ordinary level.

Messrs. De La Rue, Stewart, and Loewy also suggested, in their ‘*Researches on Solar Physics*,’ that if the photosphere of the sun be the plane of condensation of gaseous matter, the plane may be found to be subject to

periodical elevations and depressions, and that at the epoch of minimum sun-spot-frequency the plane might be uplifted very high in the solar atmosphere, so that there was comparatively little cold absorbing atmosphere above it, and therefore great difficulty in forming a spot.

This suggestion is one of great value; and, as I pointed out in my previous paper, its accuracy can fortunately now be tested. It may happen, however, that in similar periodical fluctuations the chromosphere may be carried up and down with the photosphere; and I have already evidence that possibly such a state of things may have occurred since 1860, for I do not find the C and F Fraunhofer lines of the same relative thickness as they were in that year\*. I am waiting to make observations with the large Steinheil spectroscope before I consider this question settled. But the well-known great thickness of the F line in Sirius and other stars will point out the excessive importance of such observations as a method of ascertaining not only the physical constitution, but the actual pressures of the outer limits of stellar atmospheres, and of the same atmosphere at different epochs. And when other spectra have been studied as we have now studied hydrogen, additional means of continuing similar researches will be at our command; indeed a somewhat careful examination of the spectra of the different classes of stars, as defined by Father Secchi, leads me to believe that several broad conclusions are not far to seek; and I hope soon to lay them before the Royal Society.

For some time past I have been engaged in endeavouring to obtain a sight of the prominences, by using a very rapidly oscillating slit; but although I believe this method will eventually succeed, the spectroscope I employ does not allow me to apply it under sufficiently good conditions, and I am not at present satisfied with the results I have obtained.

Hearing, however, from Mr. De La Rue, on February 27th, that Mr. Huggins had succeeded in anticipating me by using absorbing media and a wide slit (the description forwarded to me is short and vague), it immediately struck me, as possibly it has struck Mr. Huggins, that the wide slit is quite sufficient without any absorptive media; and during the last few days I have been perfectly enchanted with the sight which my spectroscope has revealed to me. The solar and atmospheric spectra being hidden, and the image of the wide slit alone being visible, the telescope or slit is moved slowly, and the strange shadow-forms flit past. Here one is reminded, by the fleecy, infinitely delicate cloud-films, of an English hedge-row with luxuriant elms; here of a densely intertwined tropical forest, the intimately interwoven branches threading in all directions, the prominences generally expanding as they mount upwards, and changing slowly, indeed almost imperceptibly. By this method the smallest details of the pro-

\* I have learnt, after handing this paper in to the Royal Society, that in Ångström's Map the C and F lines are nearly of the same breadth: this I had gathered from observations made with my own spectroscope.

minences and of the chromosphere itself are rendered perfectly visible and easy of observation.

ADDENDUM.—Received March 17, 1869.

Since the foregoing paper was written, I have had, thanks to the somewhat better weather, some favourable opportunities for continuing two of the lines of research more especially alluded to in it; I refer to the method I had adopted for viewing the prominences, and to the injection of sodium, magnesium, &c. into the chromosphere.

With regard to seeing the prominences, I find that, when the sky is free from haze, the views I obtain of them are so perfect that I have not thought it worth while to remount the oscillating slit. I am, however, collecting red and green and violet glass, of the required absorptions, to construct a rapidly revolving wheel, in which the percentages of light of each colour may be regulated. In this way I think it possible that we may in time be able to see the prominences as they really are seen in an eclipse, with the additional advantage that we shall be able to see the sun at the same time, and test the connexion or otherwise between the prominences and the surface-phenomena.

Although I find it generally best for sketching-purposes to have the open slit in a radial direction, I have lately placed it at a tangent to the limb, in order to study the general outline of the chromosphere, which in a previous communication I stated to be pretty uniform, while M. Janssen has characterized it as "*à niveau fort inégal et tourmenté.*" My opinion is now that perhaps the mean of these two descriptions is, as usual, nearer the truth, unless the surface changes its character to a large extent from time to time. I find, too, that in different parts the outline varies: here it is undulating and billowy; there it is ragged to a degree, flames, as it were, darting out of the general surface, and forming a ragged, fleecy, interwoven outline, which in places is nearly even for some distance, and, like the billowy surface, becomes excessively uneven in the neighbourhood of a prominence.

According to my present limited experience of these exquisitely beautiful solar appendages, it is generally possible to see the whole of their structure; but sometimes they are of such dimensions along the line of sight that they appear to be much denser than usual; and as there is no longer under these circumstances any background to the central portion, only the details of the margins can be observed, in addition to the varying brightnesses.

Moreover it does not at all follow that the largest prominences are those in which the intensest action, or the most rapid change, is going on,—the action as visible to us being generally confined to the regions just in, or above, the chromosphere, the changes arising from violent uprush or rapid dissipation, the uprush and dissipation representing the birth and death of a prominence. As a rule, the attachment to the chromosphere

is narrow and is not often single ; higher up, the stems, so to speak, intertwine, and the prominence expands and soars upward until it is lost in delicate filaments, which are carried away in floating masses.

Since last October, up to the time of trying the method of using the open slit, I had obtained evidence of considerable changes in the prominences from day to day. With the open slit it is at once evident that changes on the small scale are continually going on ; it was only on the 14th inst. that I observed any change at all comparable in magnitude and rapidity to those already observed by M. Janssen.

About 9<sup>h</sup> 45<sup>m</sup> on that day, with a tangential slit I observed a fine dense prominence near the sun's equator, on the eastern limb. I tried to sketch it with the slit in this direction ; but its border was so full of detail, and the atmospheric conditions were so unfavourable, that I gave up the attempt in despair. I turned the instrument round 90° and narrowed the slit, and my attention was at once taken by the F line ; a single look at it taught me that an injection into the chromosphere and intense action were taking place. These phenomena I will refer to subsequently.

At 10<sup>h</sup> 50<sup>m</sup>, when the action was slackening, I opened the slit ; I saw at once that the dense appearance had all disappeared, and cloud-like filaments had taken its place. The first sketch, embracing an irregular prominence with a long perfectly straight one, which I called A, was finished at 11<sup>h</sup> 5<sup>m</sup>, the height of the prominence being 1' 5", or about 27,000 miles. I left the Observatory for a few minutes ; and on returning, at 11<sup>h</sup> 15<sup>m</sup>, I was astonished to find that part of the prominence A had entirely disappeared ; not even the slightest rack appeared in its place : whether it was entirely dissipated, or whether parts of it had been wafted towards the other part, I do not know, although I think the latter explanation the more probable one, as the other part had increased.

We now come to the other attendant phenomena. First, as to the F line. In my second paper, under the above title, I stated that the F line widens as the sun is approached, and that sometimes the bright line seems to extend on to the sun itself, sometimes on one side of the F line, sometimes on the other.

Dr. Frankland and myself have pointed out, as a result of a long series of experiments, that the widening out is due to pressure, and apparently not to temperature *per se* ; the F line near the vacuum-point is thin, and it widens out on both sides (I do not say to the same extent) as the pressure is increased. Now, in the absence of any disturbing cause, it would appear that when the wider line shows itself on the sun on one side of the F line, it should at the same time show itself on the other ; this, however, *it does not always do*. I have now additional evidence to adduce on this point, and this time in the prominence line itself, off the sun. In the prominence to which I have referred, the F bright line underwent the most strange contortions, as if there were some disturbing cause which varied the refrangibility of the hydrogen-line under certain conditions and pressures.

The D line of hydrogen (?) also once bore a similar appearance.

Secondly, as to the other phenomena which accompanied this strange behaviour of the F line, and were apparently the cause of it.

In the same field of view with F, I recognized the barium-line at 1989.5 of Kirchhoff's scale.

Passing on, the magnesium-lines and the enclosed nickel-iron-line were visible in the chromosphere. The magnesium was projected higher into the chromosphere than the barium, and the nickel or iron was projected higher than the magnesium. I carefully examined whether the other iron-lines were visible in the spectrum of the chromosphere; they were not.

I also searched for the stronger barium-lines in the brighter portion of the spectrum; but I did not find them, probably owing to the feeble elevation of the barium-vapour above the general level of the photosphere, which made the observation in this region a very delicate one.

I detected another chromosphere-line very near the iron-line at 1569.5 (on the east side of it).

The sodium-lines were also visible.

Unfortunately clouds prevented my continuing these interesting observations; but the action was evidently toning down.

Here, then, we have an uprush of

Barium,  
Magnesium,  
? Nickel,

and an unknown substance

from the photosphere into the chromosphere, and with the uprush a *dense* prominence; accompanying the uprush we have changes of an enormous magnitude in the prominence; and as the uprush ceases the prominence melts away.

As stated in the former part of this paper, the barium- and magnesium-lines were thinner than the corresponding Fraunhofer lines. In connexion with this subject, I beg to be allowed to state that I have commenced a careful comparison of Kirchhoff's map with the recently published one of Ångström. From what I have already seen, I believe other important conclusions, in addition to that before alluded to, may be derived from this comparison; but I hesitate to say more at present, as I have not yet been able to compare Ångström's maps with the sun itself, or to examine the angular diameters of the sun registered at Greenwich during the present century.

On the 14th inst. I also succeeded in detecting the hydrogen-line in the extreme violet in the spectrum of the chromosphere.

The Society then adjourned over the Easter Recess to Thursday, April 8.