SOLAR PHYSICS—THE CHEMISTRY OF THE SUN[1]

I.

WHEN we have familiarised ourselves with the general phenomena presented to our notice by the analysis of the light proceeding from different sources, and wish to apply this know-

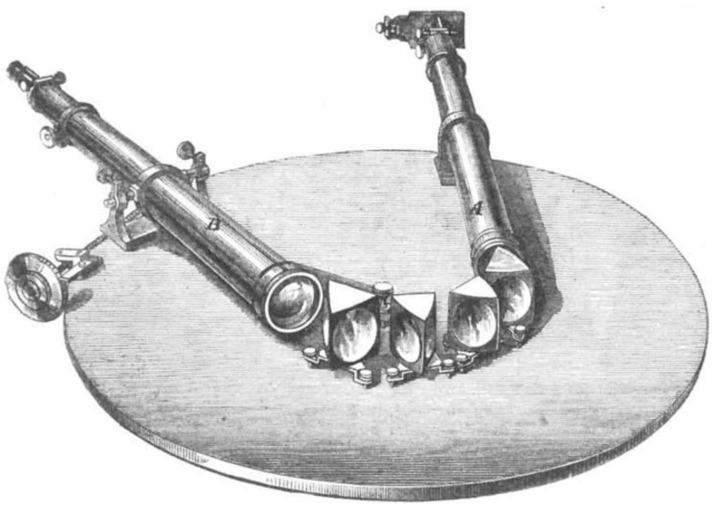


FIG. 1.—Steinheil's form of four-prism spectroscope. A, collimator; B, observing telescope.

ledge to the study of the sun, the first work to which attention must be given is a very admirable memoir of Kirchhoff (1861).[2]

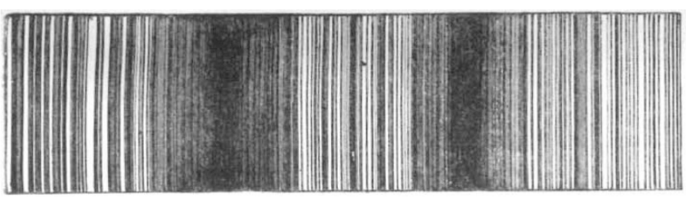


FIG. 2.—Copy of a photograph of the solar spectrum in the region of the thick calcium lines, by Lockyer.

In this, after referring to the prior work of Fraunhofer and others, he goes on to show that the same principles which had then been employed to suggest the extreme probability of the existence of sodium in the atmosphere of the sun, and the probability, therefore, that the dark line D, which we see in the spectrum, was caused by the absorption, by the cooler sodium vapour, of light proceeding from the solar nucleus which was hotter than the vapour; might be applied to other substances, such as iron, cobalt, nickel, and so on; and that if these were experimented on in the same manner, other of the dark lines in the solar spectrum might be explained.

Now I propose, in the first instance, to show what Kirchhoff saw, and what he did—his manner of work. Kirchhoff, and after him Ångström and Thalèn, to whom further reference will be made presently, used spectroscopes placed close or nearly close to the source of light. Kirchhoff's work was done by a spectroscope of this model. We have a slit and collimating lens, a train of prisms, which, of course, during the observations are carefully covered up, and the observing telescope. This instrument may be turned to the sun, or to a cloud illuminated by the sun in case the quantity of light which enters the instrument when turned directly towards the sun is too great to allow of easy observation; or light from the sun or a cloud may be reflected into the instrument by a mirror. Kirchhoff was enabled by means of properly contrived measuring apparatus to map down the positions of the lines observed.

Let us see, first of all, what kind of thing Kirchhoff saw. To give an idea of this I propose to throw on the screen photographs of that portion of the spectrum which is not so readily observable as that upon which Kirchhoff began his work. Here then is an absolutely untouched photograph of a part of the solar spectrum in the blue and violet (Fig. 2). We get in great prominence in the spectrum two very thick lines, which are called H and K, the precise position of which in the solar spectrum are shown by means of the diagram of the spectrum (Fig. 3). By moving his observing telescope along the spectrum, as it were, the telescope being furnished with a delicate micrometer, or some properly-contrived means for defining the exact position of each line, Kirchhoff was in that way able to prepare a map of the whole spectrum. Indeed he did prepare this map with the object of providing himself with a scale of extreme value for the future work which he then laid out for himself. The future work being this:—he wished to determine the positions of the bright lines given by the different chemical elements; having got this information, he

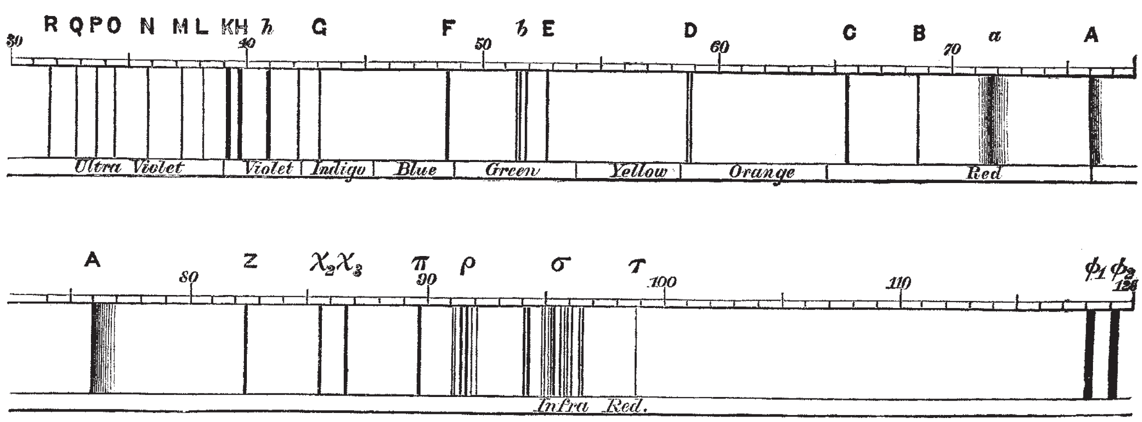


FIG. 3.—Wave-length map of the solar spectrum, including the infra-red.

wished to put the same question to the solar spectrum with regard to each of those elements as already had been done in the case of sodium. How then did he propose to do this? He made an addition to the slit of the spectroscope, such as was then employed. He put a prism in front of it, by means of which he illuminated one half of the slit with the direct light of the sun, and the other half with the light from the vapour employed

[1] Lectures in the Course on Solar Physics at South Kensington (see p. 150). Revised from shorthand notes. The first lecture is omitted, as it dealt with the general principles of spectrum analysis.

[2] "Researches on the Solar Spectrum and the Spectra of the Chemical Elements." *Transactions* of the Berlin Academy for 1861. Translation by Prof. Roscoe (Macmillan, 1862).

reflected on to that other half by means of the prism. You will see in a moment, therefore, that it was quite easy by this

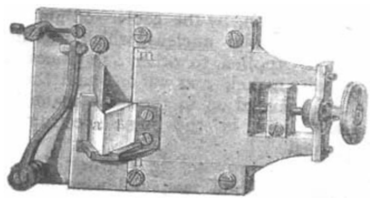


FIG. 4.—Steinheil's slit, showing reflecting prism.

method to see in his observing telescope no longer the spectrum of the sun alone, but the spectrum of the sun together with the

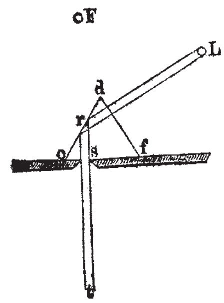


FIG. 5.—Path of light through comparison prism. *d f o*, prism, *l*, light source; *r*, point of reflection; *s*, slit; *r*, light source in front of slit.

spectrum produced by each of the chemical substances which he chose to experiment upon.

Again, anticipating matters somewhat, I can show you something like what Kirchhoff then saw—only again I give you a photograph, and therefore we have a part of the spectrum with which he did not begin his work. In the lower half of this slide we have the solar spectrum. There are the two lines H and K, and in the upper portions we have the bright lines given us by a metallic element—in this case cerium. You see when some of the metallic elements are treated in this way they have a trick of giving us very complicated spectra.

(The photograph was projected on the screen.)

I will show you the iron spectrum which Kirchhoff worked upon. The point was to determine which of the bright lines corresponded with the dark Fraunhofer lines. Over the whole visible reach of the spectrum Kirchhoff mapped the results, for iron; I will give one or two extracts from his paper. He says,[1] "It is specially remarkable that coincident with the positions of the bright lines which I have observed [that is the bright lines from the vapour of iron, using two iron poles with an induction coil] definite dark lines occur in the solar spectrum. By the help of a very delicate method of observation which I have employed, I believe that each coincidence observed by me between the iron lines and the lines of the solar spectrum, may be considered to be at least as well established as the coincidence of the sodium lines." Then he shows, limiting his attention to sixty of the most defined iron lines in the region included in his map, that the betting that there was iron in the sun was about three trillions to one, dealing alone with the absolute matching of the positions of the lines recorded in the solar spectrum. Then he goes on to show that this probability of three trillions to one was rendered still greater by the fact that the brighter a given iron line is seen to be the darker as a rule—and I beg you to mark those words "*as a rule*"—does the corresponding solar line appear. Hence this coincidence must be produced by some cause, and a cause can be assigned which affords a very perfect explanation of the phenomenon. He then gives the cause, which has already been stated by Prof. Stokes.

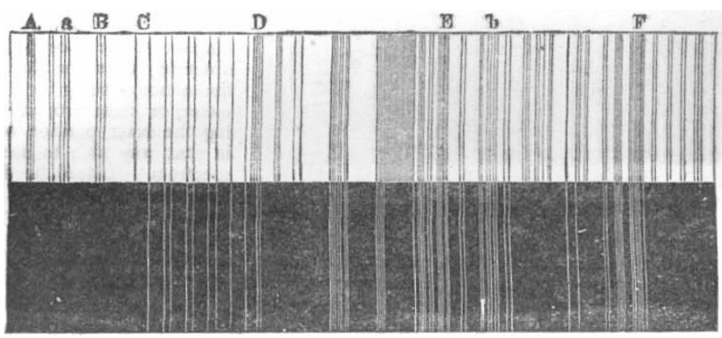


FIG. 6.—Coincidence of some of the bright lines of iron with some of the Fraunhofer lines.

Now before I go further I must point out that there is a considerable assumption here. It is quite easy in an electric lamp to produce the vapour of a meteorite or of any of our terrestrial rocks, to throw their spectra on the screen, and to map them with considerable minuteness; and we say we have the spectrum of such and such a meteorite, or of such and such a rock. Similarly we can get the spectrum of iron terminals, and serve that in the same way, and we are considerably astonished at the wonderful similarity of the results thus obtained. Now chemistry has advanced to a certain stage, and low temperature chemistry comes in and shows us that this meteorite or rock may be an excessively complicated substance. The same chemistry applied to iron shows that nothing can be done with it. But to say that iron cannot be broken up because low temperature chemistry fails to break it up is, you will see, an assumption, for as we undoubtedly get the lines of the constituents of the rock, or of the meteorite, recorded in the spectrum, we may also be registering the lines of the constituents of iron; and it is fair to say this, because we know that in the electric arc we have a stage of heat at which at present no experiment whatever has been made.

Passing on from that point, however, I will ask you to consider somewhat more in detail that part of Kirchhoff's work which deals with the connection between the solar spectrum and the spectra of the chemical elements.[2]

Confining his observations to the region of the solar spectrum between F and D, Kirchhoff found the following coincidences between lines in the spectra of certain elements and the Fraunhofer lines:—

	Lines.		Lines.
Sodium	2	Iron	42
Calcium	13	Chromium	4
Barium	7	Nickel	28
Strontium	2	Cobalt	10
Magnesium ...	3	Zinc	2
Copper	3	Gold	1

Hofmann[3] continued these researches on both sides of the region observed by Kirchhoff as far as A on one side and G on the other, and in addition investigated the spectra of the following metals:—Potassium, rubidium, lithium, cerium, lanthanum, didymium, platinum, palladium, and an alloy of iridium and ruthenium. Hofmann added the following coincidences between

1 "Researches on the Solar Spectrum." Roscoe's translation, Part I., p. 18.

2 Kirchhoff's "Researches," translated by Roscoe, Part I, Supplement.

3 *Ib.*, Part II., Appendix.

lines of the spectra of the different chemical elements and the dark solar lines :—

	Lines.		Lines.
Calcium	16	Chromium	0
Barium	5	Nickel	4
Strontium ...	2	Cobalt	4
Magnesium ...	0	Zinc	3
Copper	1	Cadmium	2
Iron	31	Gold	1

The spectra of the additional metals examined gave the following coincidences :—

	Lines.		Lines,
Cerium	2	Platinum	1
Didymium	2	Rubidium and Iridium	1
Lanthanum ...	1		
Palladium	2		

The potassium spectrum could not be obtained by moistening the electrodes with salts of this metal, and when poles of the metal were employed the spectrum was so very feeble that only two prisms could be employed, and hence the position of the lines with regard to the solar lines was not easily determined. He noted that the line Kα was better seen if the Bunsen flame was used instead of the electric spark.

In conclusion Kirchhoff and Hofmann state that, although the additional observations have added nothing to what the previous work had taught, they have confirmed the results of the previous examination. A large number of lines of iron and of calcium occur in the yellow and the blue, and all these were found coincident with well-defined Fraunhofer lines. The probability that nickel is present in the solar atmosphere is greatly increased by the number of new coincidences observed. Cobalt remains doubtful, the solar lines coincident with a considerable number of its bright lines not having been observed. New coincidences in the spectra of barium, copper, and zinc with dark solar lines confirm the presence of those elements in the sun's atmosphere. In the cases of strontium and cadmium the number of coincidences seemed to be too small to warrant the conclusion that those metals are in the sun. The other chemical elements examined, including potassium, did not appear to be visible in the solar atmosphere. The case of potassium however they consider as doubtful, since faint solar lines are very near the red potassium lines.

Note that the passage from the spectrum of the spark to the spectrum of the sun lands us in doubt in many instances.

Kirchhoff next discusses the bearing of this work on the physical and the chemical condition of the atmosphere of the sun. Of course this at once destroyed, at a blow, the idea of Sir William Herschel that the sun was a cool habitable globe with trees, and flowers, and vales, and everything such as we know of here. If the atmosphere were in a state of sufficient incandescence to give these phenomena it was absolutely impossible that anything below that atmosphere should not be at the same time at a higher temperature. He says, "Judging of the height of the solar atmosphere from the phenomena observed in a total eclipse of the sun, it cannot be small in comparison with the radius of the body, and hence the distances which two rays have to pass, one of which proceeds from the centre, and the other from the edge of the disk, do not greatly differ." That was a reply to an objection which had been urged to the effect that if a dark line had been produced by anything absorbing in the atmosphere of the sun, there would be a very considerable difference between the spectrum of the sun's limb and the spectrum of the sun's centre, for the same reason, *ceteris paribus*, that the sun is white at noon-day and reddish at sunset; for since our atmosphere is thin, the light passes through a greater stratum in the one case than in the other. At the sun the light would have to do the same thing, and we should get, therefore, a greater darkening of the limb than is actually observed. He says :—"In addition to this we must remember that the lowest layers of our terrestrial atmosphere are those in which the distance traversed by the light increases most rapidly when approaching most nearly the horizon; for the solar atmosphere, on the contrary, it is those layers which are elevated to a certain position above the solid crust of the sun which are more energetic in producing dark lines than the lower layers which possess a temperature slightly different, and effect but little alteration on the light." He therefore places the region where this absorption takes place at a considerable elevation in the atmosphere of the sun. His notion is that the sun we see is what gives us the continuous spectrum the light of which is absorbed; that above that there is a haze different in structure from it, and yet not competent to give us the absorption lines; that practically none of the absorption phenomena arise from that stratum, but that above this very luminous region of haze the absorption phenomena take place. Such was Kirchhoff's view.

We now pass on for some years to the next step, the work of another eminent man no longer amongst us, Ångström.[1] He took up very nearly the same work as Kirchhoff did, and extended it in certain directions; but he did the work in a different way instrumentally. He was not content with the kind of scale which Kirchhoff had employed, a scale dependent on the construction of his instrument. He wished to have a natural scale. He therefore rejected the use of prisms, and used a diffraction grating. By means of this he obtained what was called, and what is still called, a normal spectrum; and having obtained this he, as Kirchhoff had done before him, endeavoured to determine the coincidence, or want of coincidence, of metallic lines.

By the use of these diffraction gratings measured with great care and expressed in terms of the standard metre, along with a collimator and reading-telescope, the latter fitted with a micrometer screw which enabled the operator to determine with great accuracy the angle through which it moved, Ångström was able to determine with great exactness the wave-lengths of the more prominent line of the solar spectrum from A to H. Using these lines as starting-points he was able, by means of the micrometer, to measure the angle between any of these points and any line which lay between them, and then writing these determinations in interpolation formulæ he was able to compute the wave-length of any observed solar line.

The wave-lengths are given to the second decimal place, the unit being $\frac{1}{10000000}$th of a millimetre.

In the atlas which accompanies this memoir of Ångström the scale is divided, so that one division corresponds to $\frac{1}{10000000}$th of a millimetre of wave length. In addition to marking the wave-lengths of the solar lines, their relative intensities are shown. The map also shows the origin of each line and its correspondence with the lines of metallic spectra so far as these have been determined by Ångström and Thalèn.

The following is a summary of the coincidences observed[2] :—

	Lines.		Lines.
Hydrogen	4	Manganese... ...	57
Sodium	9	Chromium	18
Barium	11	Cobalt	19
Calcium	75	Nickel	33
Magnesium ...	4 (3?)	Zinc	(2?)
Aluminium ...	2 (?)	Copper	17
Iron	450	Titanium	118

Ångström remarks that the number of these lines, about 800,[3] might easily be increased by raising the metals to a higher stage of incandescence. Still, he observes, the number already found is quite sufficient to enable him to refer the origin of almost all the stronger lines of the solar spectrum to known elements, thus confirming the opinion he had expressed in a previous memoir, that the substances which constitute the mass of the sun are doubtless the same as those forming that of the earth. But, he says, the fact must not be lost sight of that there exists, nearly midway between F and G, strong solar lines of which the origin is entirely unknown: still it would be premature to assert that the substances to which these are due are not constituents of our globe.

Of aluminium he says[4] that although it gives brilliant lines in different parts of the spectrum, yet the two lines situated between Fraunhofer's two H-lines are the only ones which appear to coincide with solar lines. By way of explanation of this phenomenon he points out that the violet rays are much the strongest in the spectrum of this metal. He observes that these two lines often present the same phenomenon of absorption as is shown by the yellow sodium lines, which is a proof of their great intensity. He states finally that the point will be cleared up by ascertaining whether the ultra-violet lines of aluminium coincide or not with faint solar lines in that region.

Of zinc he remarks[5] that the two lines he has given of that metal as coincident with solar lines do not correspond with the latter in character, being wide, very strong and nebulous, so that

[1] "Recherches sur le Spectre Solaire" (Upsal, 1869).
[2] *Ib.*, p. 35. [3] *Ib.*, p. 36.
[4] *Ib.* [5] *Ib.*

the presence of zinc in the sun remains doubtful. It is noteworthy, however, that there are three lines in the magnesium spectrum which present the same nebulous appearance, and to which there are no corresponding solar lines, and yet magnesium is undoubtedly present in the sun.

Kirchhoff's and Ångström's maps are in all our laboratories, and there is a very considerable difference between them. This difference arises from the fact that whereas Kirchhoff used an induction coil and spark, Ångström varied his experimental method by placing no longer a spark, but the electric arc in front of the slit of his instrument. In this case, therefore, he was determining the spectrum which was produced at the temperature of the electric arc instead of the spectrum which was produced at the temperature of the induction coil. The result of their combined attack is shown in the accompanying table :—

Elements present in the Sun

Kirchhoff.	Ångström and Thalèn.
Sodium.	Sodium.
Iron.	Iron.
Calcium.	Calcium.
Magnesium.	Magnesium.
Nickel.	Nickel.
Barium.	—
Copper.	—
Zinc.	—
	Chromium.
	Cobalt.
	Hydrogen.
	Manganese.
	Titanium.

So far then for that mode of observing the sun which consists in comparing the total light of the light-source with the total light of the sun.

This introduces an important consideration. When we have a light source placed in front of the slit of the spectroscope it is perfectly clear that light from all portions of the light source must illuminate the slit. Similarly, if we content ourselves by pointing the spectroscope to the sun, or to a cloud illuminated by the sun, it is perfectly obvious that the light from all parts of the sun must enter all parts of the slit.

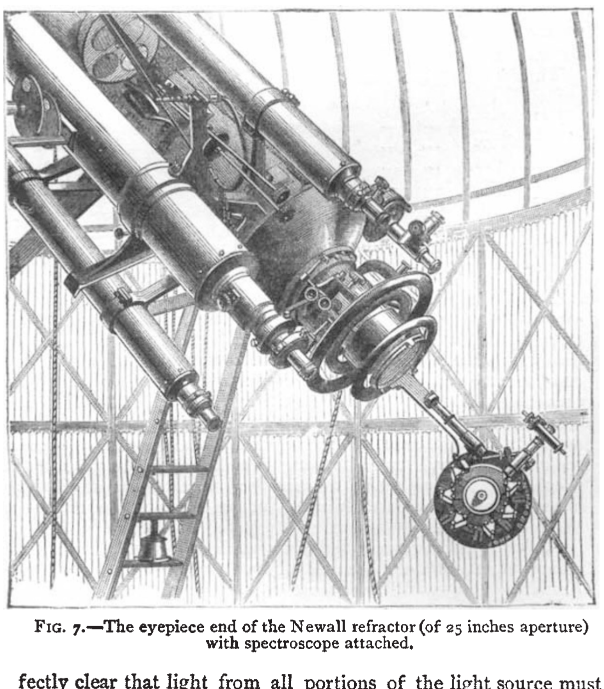


FIG. 7.—The eyepiece end of the Newall refractor (of 25 inches aperture) with spectroscope attached.

Is there any other way of observing the sun along with the light source? You will see in a moment that there is. *We can throw an image of the sun on the slit of the spectroscope.* This work was begun in 1866. If an image of the sun contains, let us say, a spot or a facula, we can see it when we throw it on to the slit. If we can manage to do so we shall get the spectrum of the sun-spot as distinguished from the spectrum of the other portions of the sun, or we shall get the spectrum of the facula as opposed to the spectrum of the other portions of the sun. The manner in which this kind of work is carried on is easily grasped. It simply consists in the use of a spectroscope of large dispersion attached at the focal point of a telescope of considerable power. Here is the eye-piece end of Mr. Newall's refractor, with a spectroscope, with a considerable number of prisms, fixed to the telescope by means of an iron bar, with the slit of it in the position of the focus, so that when the instrument is pointed towards the sun we see an image, in the case of this telescope something like four inches in diameter, with the spots and brighter portions wonderfully and beautifully clear, and by means of the different adjustments of the telescope we can bring now a spot, and now one of the brighter portions of the sun on to the slit, and see if there be any difference between the spectrum of the spot and the spectrum of the general surface of the sun.

If we wish to observe two adjacent spots and compare their spectra, we can rotate the spectroscope and look at both. Again, anticipating matters, I can show what we see to a certain extent, for latterly we have been fortunate enough to obtain some photographs of the spectra of sun-spots.

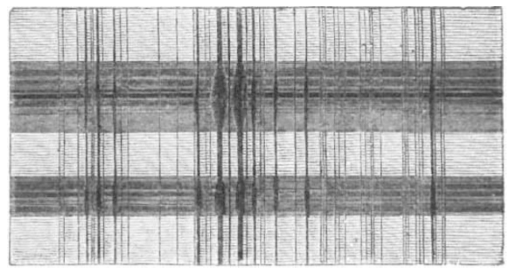


FIG. 8.—Spectrum of Sun-spot, showing the widening of the D lines.

The dark portion gives us the spectrum of the spot throughout the whole length of the spectrum. That is a case of continuous absorption. The continuous radiation of the sun is cut off, but independently of this continuous absorption some of the lines are considerably thickened in the nucleus of the spot (Fig. 8). Now the lines observed in the first instance were the lines of sodium, and the point of the observation was this. Two rival theories had been suggested to explain how it was that the sun-spot was dark. One school said it was due to absorption, and another that it was due to the defect of radiation from the interior gases of the sun. If we had been dealing with defective radiation, we should still have been dealing with radiation, and should have expected to see bright lines; but no obvious bright lines were seen in the spectrum of the spot; what we did see was the thickening and darkening of the lines and the continuous absorption. In the case of the lines of sodium it was very marked; so that we were perfectly justified in saying that the sun-spot was really not produced by any defect of radiation, but was truly and really produced by an increased amount of absorption.

I hope to show you that we can vary the thickness of this line in precisely the same way that it is varied in the different sun-spots, and if then we examine the conditions under which we can experimentally make the line thicker, we shall in that way get some explanation of the thickening of the line in the solar spot. This experiment is rather a difficult one. We will volatilise some sodium in the electric arc and throw its spectrum on the screen. I hope to show that the absorption line is very thick to start with, and then it becomes very thin; if I give it time it will thin down gradually. What is the cause of the thickening and the thinning? It is perfectly obvious. The temperature is practically the same all the time, but we have a very considerable quantity of sodium vapour surrounding the incandescent poles in the first instance. On the further application of the heat this sodium vapour goes away by degrees, and we gradually deal with a smaller quantity, and as we deal with a smaller quantity the line thins. We therefore are justified in saying that when in a sun-spot we get the line of sodium considerably thickened, that is due to the fact that in a sun-spot there is a greater quantity of sodium vapour present.

That was the first experiment with which I am acquainted which enabled us to locate chemical phenomena in any particular part of the sun.

Now although in the year 1866 a great many people were familiar with the spots on the sun, those who had been favoured by a sight of a total eclipse, and many more who had read the accounts of total eclipses, knew that there was a great deal more of the sun than one generally sees. From the time of Stannyan, who observed the prominences at Berne, down to the year 1842, let us say, several eclipses had been observed, and very beautiful coloured phenomena had been recorded by different observers. Red things had been seen projecting round the dark moon during the time of eclipse, and although many held them to be beautiful effects produced by the passage of the moon over the sun, or even clouds in the atmosphere of the moon coloured by the strange way in which the solar light then fell upon them, a larger number of people, on the other hand, insisted that these things must really belong to the sun. Now if that were so, it was perfectly clear that we should not be contented with merely observing the chemical nature of the spots.

Having the spectroscope, the things which showed thus, and which up to that time had only been observed during eclipses, would be more or less *felt*, if they were not absolutely rendered visible, by this new instrument; and for this reason: the things seen round the sun during an eclipse were not there for the instant of the eclipse only: they were always there: why did we not see them? The illumination of our own air prevented this. What was our own air illuminated by? By the sunlight. Now whereas increasing dispersion does considerably dim a continuous spectrum for the reason that it makes it extend over a larger area on the screen, it does not dim to any great extent the brightness of a line, so that by employing a considerable number of prisms we ought to be able to abolish the illumination or our air altogether, and in that way we should no longer be limited to determining merely the chemical nature of the spots, we should be equally able to determine the nature of the surrounding solar atmosphere, supposing the phenomena observed during eclipses were really solar, and not lunar or terrestrial.

I will make an experiment with the electric light. I begin with a bright continuous spectrum. We will charge the cup in the lower pole with some vapour which will give us a bright line, in addition to the continuous spectrum due to the poles, and these two things must fight it out between them. If everything goes well what should happen will be this: by first mounting one prism, then two, and then three, the continuous spectrum will be gradually enfeebled, the line keeping the same luminosity during the whole time; we shall find that relatively the line will be much brighter than the continuous spectrum by the time the experiment is concluded. That was the principle which it was suggested would enable the spectroscope to be used in making what have been called artificial eclipses.

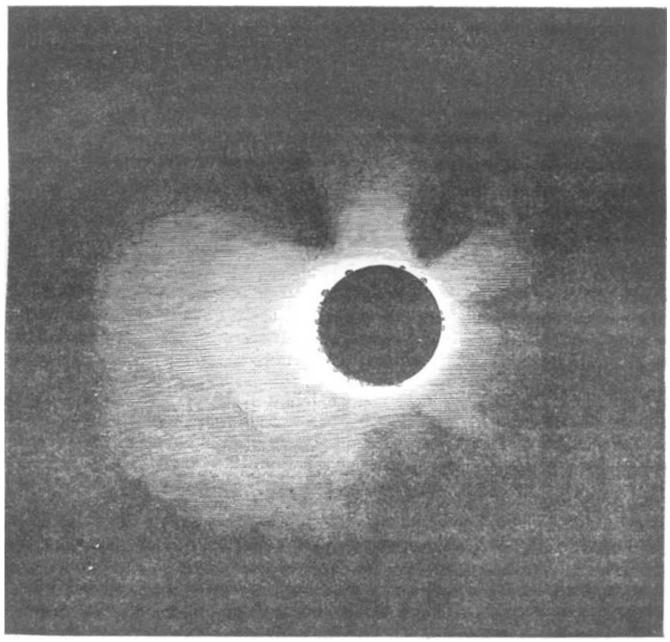


FIG. 9.—Eclipse of 1870. *Photograph of the corona taken at Syracuse.*

Now if we ask what are the phenomena presented by eclipses, the sort of thing the spectroscope is called upon to observe, we shall see the very considerable advantage of the introduction of the new method. In the first place the eclipses, which are so full of the precious knowledge to be got only at that moment, are almost instantaneous, so far as each particular phenomenon is concerned; and, secondly when the duration is say, four or five or six minutes, which is a very considerable time during an eclipse, and which allows a great deal of work to be done; only a very small part of the more interesting regions of the solar atmosphere is uncovered; one part, of course, when the moon is passing over one limb of the sun, and the other when the moon in passing, liberates it, and brings it into light again. What I would draw chief attention to is the lower part of the brilliant portion seen around the dark moon. We shall have to discuss the upper portion, which is called the coronal atmosphere, or corona, on a later occasion. This mere visual reference, of course, is simply in anticipation of the chemical nature of the different strata upon which we have to operate by the spectroscope, and about which I shall have therefore to tell you in that part of the lecture which has to do with localisation. We shall thus determine, after what has been already said with regard to Kirchhoff's hypothesis as to the position of the region where the lines ought to be seen in the corona, whether during an eclipse we get anything like a justification of this hypothesis. This drawing is really a very beautiful reproduction of an eclipse. We have a round dark moon, which in this case is represented as entirely covering the sun; then these different prominences and luminosities, this wonderful set of streamers, or whatever you like to call them, which seem to veil, or to render less distinct, something else which is lying beyond them. You will see here that some of these prominences are red, and others have a yellow tinge, and that, quite independent of the colour of the prominences, we have the most exquisite coloured effects. Sometimes the radial structure is not so marked, and reveals indications of structure further away from the sun. You see wonderfully delicate tracery, lines being seen now in one part and now in another. In the photograph taken during the eclipse of 1870 we see that the luminosity of the solar atmosphere was excessively irregular, by which I mean that in one part we get a very considerable excess of light, quite independent of the sharply defined prominences, whereas in other portions the atmosphere of the sun at the same height is not nearly so luminous. Now in none of these cases have we been able to see the thing which struck us most clearly the moment the artificial eclipse system was set at work.

The drawings of the eclipse of 1842 show us that before it was possible to observe the edge of the sun without the intervention of the dark moon there was much evidence which went to show that these red prominences or flames, these different coloured phenomena, were really, so to speak, upper crests of an almost continuous sea round the sun.

In the drawings in question, connecting the prominences,

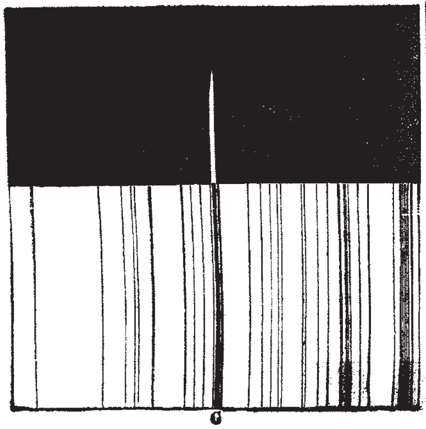


FIG. 10.—Line C (red), with radial slit.

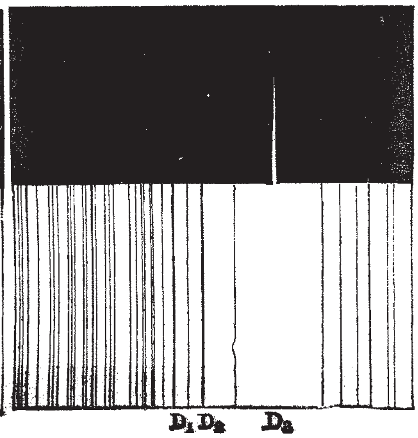


FIG. 11.—Line D_3 (yellow), with radial slit.

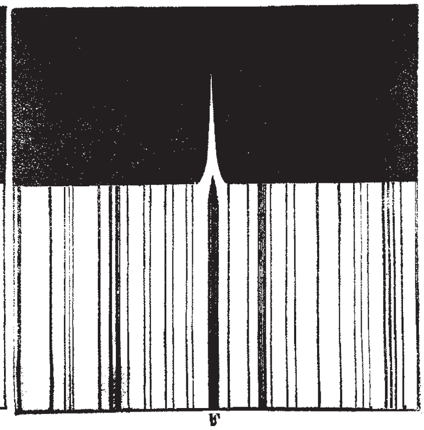


FIG. 12.—Line F (blue-green), with radial slit.

there is a fine low level of the same colour as the prominence itself. The other drawings give us those prominences after the moon had covered all the lower portion, and that is as good an indication as I can think of of the extreme difficulty of making observations during eclipses, and how important it is that one should have a method which makes us independent of them.

How then is this method carried on? It should be perfectly clear that if instead of using our slit to bisect a spot we allow the slit to fall on the edge of the sun, and then fish round it, if the method is competent to abolish the illumination of our atmosphere, to make the bright lines visible, that here and there if we catch a prominence the slit will be illuminated by the light of the prominence; and if we have the image of the sun very accurately focussed on the slit, if we know the size of the image of the sun, and if we know the length of our slit, the length of the slit illuminated by the prominence will enable us readily to determine the exact height of the prominence; so that if it should happen that there is a sort of external invisible sea round the sun usually invisible, but which this new method will pick up, that we shall get the depth of the sea sounded for us by the length of the line on the slit; and further, if that sea is not absolutely level, but if it swells here and there into waves and prominences, the slit will enable us to determine the height of the prominences. Some copies of very early drawings show exactly what is seen when a prominence is thrown on the slit, and show very well the point at which I have been driving.

Again, if we do fish round the sun in this way, and if these prominences really do give us lines, we have exactly the same method of determining the chemical nature of this exterior sea as Kirchhoff employed in determining the composition of the general light of the sun; only we have this great addition to our knowledge in this case, that whereas Kirchhoff had to suggest an hypothesis to explain the possible locus of the region which produced the lines due to the different chemical substances, we have the hard fact beneath our eyes, because if we pass over the prominence, and if it is built up of iron, let us say, then we shall see iron lines; if it is built up of calcium, then we shall see calcium lines, and so on. Now what are the facts? Here is the first observation that was recorded with absolute certainty touching the chemical nature of the exterior envelope of the sun. We find that we are dealing with the line C; and although Kirchhoff did not tell us the origin of this solar line, he showed that it was quite possible to determine the origin of the lines even if they were produced by gaseous bodies. Ångström went further, and added gaseous bodies to the subject of his investigation, and he found by using a Geissler tube he got a line in the red exactly coincident with the line C in the spectrum of the sun. When therefore we had such an observation as this, showing one of the lines produced by this external sea, coincident with the C line of the solar spectrum, we knew at once

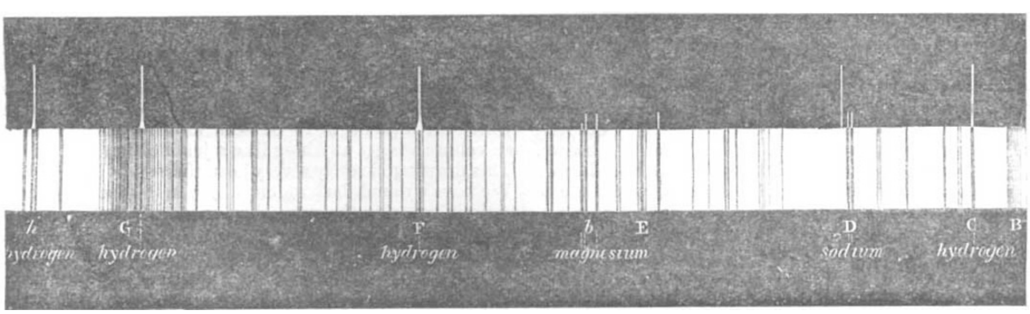


FIG. 13.—Spectrum of the sun's photosphere (below) and chromosphere (above).

that that line was produced by hydrogen. It was obvious, of course, that at once the other lines of hydrogen should be investigated. The next obvious line of hydrogen is F in the blue green, and when the question was put to this line, in that case also it was found that the prominences gave out no uncertain sound—that the prominences were really and truly composed to a large extent of what we call hydrogen; that is to say, the spectral lines observed when we render hydrogen incandescent are identical with the spectral lines observed when we throw one of the solar prominences on the slit. It was soon found that this continuous ocean, this continuous outer shell of the sun, varied considerably in thickness from time to time, and it was also found that other substances besides hydrogen, some of which at present we know nothing of, others of which we now think we know a great deal of, also appear side by side with the lines of hydrogen. I have already stated that other substances besides hydrogen have been determined to exist in this lower chromospheric layer. In almost all cases, however, we find that these lines are never so long as the hydrogen line, from which we gather that the magnesium sea, to take a case, is a much shallower one than the hydrogen sea. I should further add here that when the sun is moderately active and can be well

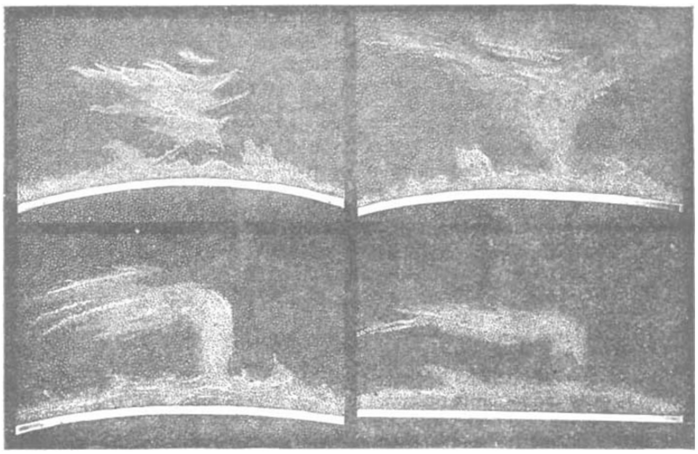


FIG. 14 —Solar prominences (Young), showing lateral currents.

observed, as in a fine climate like that in Italy, this magnesium sea can be detected all round the sun, so that we have in the chromospheric layer, first of all, a sea of hydrogen with its prominences, and then at the bottom of this sea another sea of magnesium, which wells up sometimes where the prominences are strongest.

The different forms which these prominences assume are very striking. You will have no difficulty in seeing that there is really a fundamental difference between them, and that all present us with indications of movement, and these movements enable us to apply a test to the theories of the formation of spots and prominences to which Prof. Stokes referred. Prof.

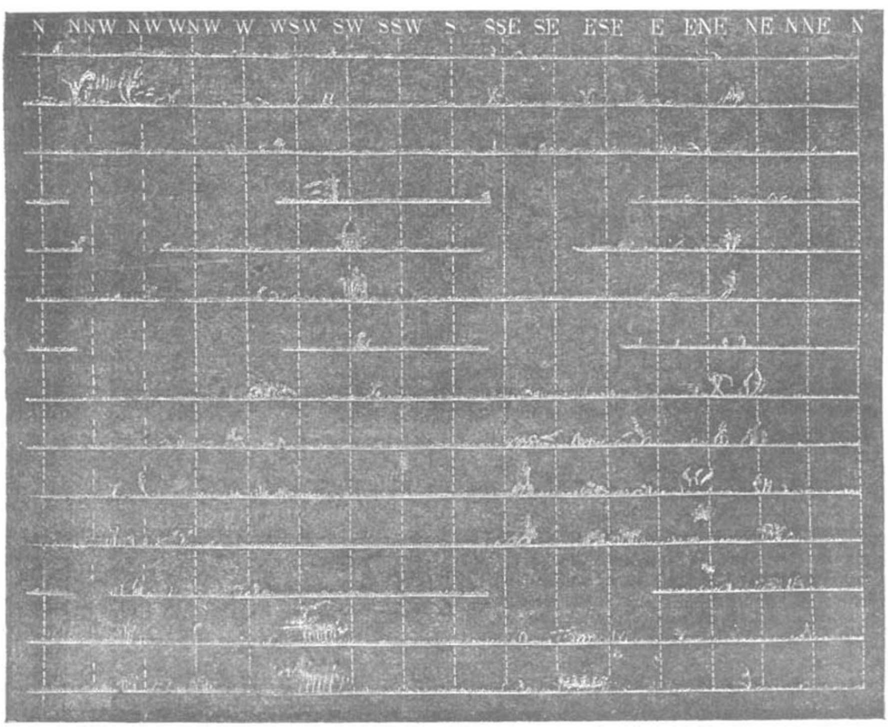


FIG. 15.—Diagram showing how the prominences are daily recorded (Respighi).

Stokes pointed out that a great many phenomena require that the sun-spot shall consist of descending currents, and that these prominences, which when we can see them are fed by the incandescent matter of the sun, should not be descending currents like those in spots, but should be ascending currents,—in fact masses of incandescent vapour shot out from the very bowels of the sun itself. The drawings, which we owe to the skill of Prof. Respigi, drawn by the simple contrivance of opening the slit after we have got the image of the prominence carefully upon it, give us a great many cases of upward movement and lateral movement, sometimes excessively intense, giving indications of their being carried either to the right or to the left of the picture by horizontal currents.

Such then is a first preliminary survey of the method of observing the chemistry of the sun, not as a whole, but of each particular little bit of the sun, chosen here and there, and brought upon the slit of the spectroscope.

J. NORMAN LOCKYER

SOME OBSERVATIONS ON THE MIGRATION OF BIRDS[1]

WHILE showing some friends the astronomical observatory and accessories connected with the College of New Jersey at Princeton, on the night of October 19, 1880, after looking at a number of objects through the $9\frac{1}{2}$-inch equatorial, we were shown the moon, then a few days past its full phase. While viewing this object my attention was at once arrested by numbers of small birds more or less plainly seen passing across the field of observation. They were in many cases very clearly defined against the bright background; the movements of the wings were plainly to be seen, as well as the entire action of flight. In the same way the shape of the head and the tail were conspicuous, when the bird was well focussed. As the moon had not been very long above the horizon the direction of observation was consequently toward the east, and the majority of the birds observed were flying almost at right angles to the direction in which the glass was pointed.

Here then was opportunity for the determination of two points—the kind of birds that were flying, and the general direction in which they were moving. Respecting the first, it was comparatively easy to decide as to what families the species belonged. This point was gained by observing the general shape of the birds, their relative size, the motion of their wings, and their manner of flying; that is, whether the flight was direct or undulating, by continuous strokes of the wings or by an intermittent motion of those members.

Most of the birds seen were the smaller land birds, among which were plainly recognised warblers, finches, woodpeckers, and blackbirds; the relative numbers being in the order of kinds above named. Among the finches I would particularly mention *Chrysomitris tristis*, which has a very characteristic flight; and the blackbirds were conspicuous by the peculiar shape of the tail, from which characteristic I feel most positive in my identification of *Quiscalus purpureus*. I mention such details to explain just how observations were made and conclusions arrived at.

In regard to the second point, with rare exceptions the birds were found to be flying from north-west to south-east. I do not mean that this was absolutely the direction, but that it was the approximate and general one.

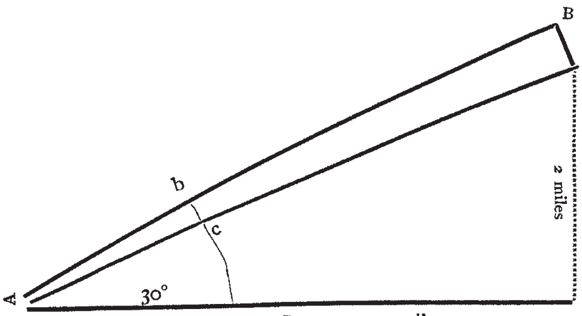
It is not within the scope of the present paper to do more than give details on two other points, namely, the estimated number of birds passing through a given space during a given time, and the height at which the birds were most abundant. For the basis of the first of these points it was necessary to note, first, how many birds passed through the field of observation per minute, and second, how near or how far distant from the glass the birds would have to be in order to be seen at all, that is to be in focus.

The height of the moon above the horizon in degrees and the two limits of the area of observation—that is how near or how far the birds noted were from the glass—supply the data for determining how high the birds seen were flying, and this, combined with the number noted as passing per minute through the field of observation, gives the basis for computing how many birds were passing through a square mile in a given time.

In this connection it may be well to specify how the two limits of observation were defined. The inferior limit, that is, the nearest point where objects could be seen with distinctness, was easily determined by the power of the glass; this is about one mile distant. The superior limit, or the most distant point, is provisionally assumed to be not more than about four miles away, on the hypothesis that the birds would not fly at a greater height than ten thousand feet. It may appear, as future observations are made, that this last limit is not correct, but the reasons for assuming such a height as the superior limit are sufficient to warrant its use in this case, for birds were observed on this same night at a late hour when the height of the moon above the horizon would make the point at which the birds were noted almost at this great elevation, viz. ten thousand feet.

I am greatly indebted to Prof. Charles A. Young for assistance in these observations, and with his aid have arrived at the conclusion that the average number of birds passing through the field of observation per minute was four and a half. Prof. Young has also kindly assisted me with the details of the problem in regard to the limits and area of the field; and the following diagram and computations are from his study of the matter.

Moon's altitude = 30°; moon's semi-diameter = 15′ 05″. The area of observation is a flat triangle = B, A, C. From this must be deducted the small triangle b, A, c, the area within a mile of the glass. The flight of the birds is thought to be nearly at right angles to the field of observation.



Area of triangle B, A, C = 0·07020 miles.
Area of triangle b, A, c = 0·00439 miles.
Therefore b, B, C, c = 0·06581 = $\frac{1}{15\cdot2}$ mile.
Distance from A to B = four miles.
Number of birds seen per minute = $4\frac{1}{2}$.
Number of birds per square mile per minute = 68.

W. E. D. SCOTT

[Mr. Scott's novel and important observations definitely establish on a scientific basis several points in relation to the migration of birds that have heretofore rested almost wholly on conjecture and probability.

We have, first, the fact that the nearest birds seen through the telescope must have been at least one mile above the earth, and may have ranged in elevation from one mile to four miles. It has been held that birds when migrating may fly at a sufficient height to be able to distinguish such prominent features of the landscape as coast lines, the principal watercourses, and mountain chains over a wide area. Of this, thanks to Mr. Scott, we now have proof. It therefore follows that during clear nights birds are not without guidance during their long migratory journeys, while the state of bewilderment they exhibit during dark nights and thick weather becomes explainable on the ground of their inability to discern their usual landmarks—points that have been assumed as probable, but heretofore not actually proven.

These observations further indicate that many of our smaller birds migrate not only at night but at a considerable elevation—far beyond recognition by ordinary means of observation. A promising field is here opened up, in which it is to be hoped investigation will be further pushed, not only by Mr. Scott but by others who may have opportunity therefor.—J. A. ALLEN.]

[1] From the *Bulletin* of the Nuttall Ornithological Club for April.

ON THE EQUIVALENTS OF THE ELEMENTARY BODIES CONSIDERED AS REPRESENTING AN ARITHMETICAL PROGRESSION DEDUCIBLE FROM MENDELEEFF'S TABLES

THE relatively quick succession of new elementary bodies which has marked the last decade of scientific progress and which must be considered as the result of chemical research, pioneered and guided by spectroscopic study, has brought very prominently into notice Mendeleeff's most remarkable law of the periodicity of the chemical elements.

Originally published in Russian in 1871, his memoir has since been translated and reprinted by the author in the *Moniteur Scientifique* (July, 1879), and thence has been translated into some of the English journals.