ON THE SPECTROSCOPE AND ITS APPLICATIONS

V.

SPECTRUM analysis, then, teaches us this great fact, that solids and liquids give out continuous spectra, and that vapours and gases give out discontinuous spectra; that is to say, that we get bright lines in different parts of the spectrum, instead of having an unbroken light all over the spectrum. I might vary this statement by stating broadly that the radiation or giving out of light by solids and liquids is a general one, and that the radiation or giving out of light by gases and vapours, instead of being general, is in the main a selective one.

The tubes, to which reference has already been made, put us then in complete possession of a point which has already been arrived at by two different lines of investigation. A few years ago Dr. Frankland, in investigating the spectrum of hydrogen, which, as you know, according to the statement I have just made, ought to give a discontinuous spectrum, discovered that, when observing the spectrum under very great pressure, he got a white light, and a continuous spectrum. Afterwards Dr. Andrews, another fellow of the Royal Society, who was working at the theory of vapours and the theory of liquids from a perfectly different stand-point, and who never thought of using a spectroscope at all, arrived at the conclusion that it was quite possible that vapours might be so condensed in almost every case, that by crushing them together, so to speak, you might really arrive at a liquid form of the vapour which you might choose to investigate. I hope you will not think that these high physical investigations are not practical enough. Let me remind you that we do not know what they may lead to.

Not only did Dr. Frankland determine that very dense gases and very dense vapours gave continuous spectra, but in another research, in which I have had the honour of being associated with him, we have shown that the spectrum of a vapour or of a gas does very much more than tell us merely what the gas or vapour experimented upon is; it in fact tells us something of the physical condition of that gas or vapour, that is to say, whether it is very rare or whether it is very closely packed together—whether it exists under a low or a high pressure. Very fortunately for us, this is an investigation which has not only an immense application in every chemical experiment with which the spectroscope has to do, but it has its story to tell and its aid to give concerning every star that shines in the heavens. We may state generally that, beginning with any one element in its most rarefied condition, and then following its spectrum as the molecules come nearer together, so as at last to reach the solid form, we shall find that spectrum become more complicated as this approach takes place, until at last a vivid continuous spectrum is reached.

Spectrum analysis, then, if it merely differentiated between gases, vapours, solids, and liquids, and between gases and vapours in different states of pressure, would really be a new chemistry altogether; and I have no doubt that the time is not very far distant when, not only in the chemist's laboratory, but in a great many applications of the physical sciences, the spectroscope will be considered as necessary, and will be almost as much used, as a chemical balance, and the sooner that time comes the better.

But not only are we able to differentiate between different bodies, but the most minute quantities of substances can be determined by this method of research. The thing seems so impossible, that you may, some of you, feel inclined to doubt my assertion when I tell you, for instance, that Kirchhoff and Bunsen have calculated that the 18-millionth part of a grain can be determined by the spectroscope in the case of sodium; that is to say, if in anything which I choose to examine by means of my spectroscope the quantity of sodium present amounts only to the 18-millionth of a grain, the spectroscope is perfectly competent to take up that minute quantity, and bring it out into daylight, so as to be detected with certainty. This reaction of sodium is so delicate, that if we examine any flame, burning in air, we almost invariably find sodium in it, for every particle of dust is impregnated with a sodium salt, probably sodic chloride. This is not to be wondered at, as two-thirds of the earth's surface is covered by sea, which contains a considerable amount of sodium salts, and the fine spray, which is continually caused by the dashing of the waves, evaporates and leaves *minute* specks of salt which are carried over the whole land, and make themselves visible in our spectroscopes. Take another instance. Lithium is a substance the knowledge of the existence of which as a common element we owe entirely to the spectroscope; the 6-millionth part of a grain of this can be detected. If we examine anything for lithium, and do not get the characteristic red line, we know that not even the 6-millionth of a grain is present. Strontium, again, can be discovered if only a millionth part of a grain is present. So much for the great power of spectrum analysis in its physical applications, and its dealing with minute quantities of the elements which we know already, and this of itself would be of enormous importance.

But the spectroscope does not stop here; it discovers the known elements under conditions where detection seemed almost impossible, and in which the old chemistry was powerless to help us. Let us take, again, for instance, lithium. Lithium was only known formerly to exist in four minerals; it is now known, thanks to the spectroscope, to exist almost everywhere. If we were to take the ash of a cigar and introduce it into a colourless gas flame and examine the colouration with the spectroscope, we should get a spectrum of lithium; and if we analysed in the same way the ash of milk, or the ash of blood, or of grapes, tea, sugar, &c., we should also find it. Dr. Miller has shown that, in the Wheal Clifford mine 800 lb. of this salt are given every 24 hours, though before the advent of spectrum analysis no lithium was known to exist there. It has also been found in meteoric stones, in the water of the Atlantic, &c. Surely this is an application of very great importance.

Another extremely important point about spectroscopic analysis is that, although we may have to analyse a complicated mixture of substances, the spectroscope is perfectly competent to deal with them. The characteristic lines for each element must stand out and be visible whether the substance be simple or complex. Thus, for instance, if we mix together some sodium and lithium, and place some of the mixture in a flame, we shall see nothing but the brilliant yellow colour due to sodium, the crimson flame of the lithium being entirely hidden. A moment's examination with the spectroscope, however, is sufficient to show us that both lithium and sodium are, without the slightest doubt, present in the flame; for both the yellow and red lines stand out as distinctly as they did when the simple salts were experimented with. The presence of lithium, indeed, may be detected, even if it be mixed with ten thousand times its bulk of sodium compounds.

But, further, spectrum analysis is not satisfied with showing us sources of known elements. It discovers new elements altogether. In 1860, Bunsen happened to be examining with a spectroscope the result of one of his analyses of the waters of a spring near Dürkheim, and he saw some lines which he had never seen before, although he had very carefully mapped the spectra of the known elements. Bunsen, as you know, is a very resolute chemist, and what he did was this. Having faith in his instrument, he evaporated no less than forty-four tons of the water of this spring, and out of these forty-four tons he got about two hundred grains of what turned out to be a new metal, which he called Cæsium. Rubidium was the next metal which was discovered in this way. Take another instance, the discovery of thallium by Mr. Crookes. Mr. Crookes was working with a seleniferous deposit from the Hartz mountains, when, by the aid of the spectroscope, he discovered this metal, which, I am informed, is now extensively used in the manufacture of fireworks. The spectrum of this metal is extremely distinct and beautiful, and you will understand why it has been named thallium, from the Greek word for a twig, on account of the beautiful green colour of the single line ordinarily visible.

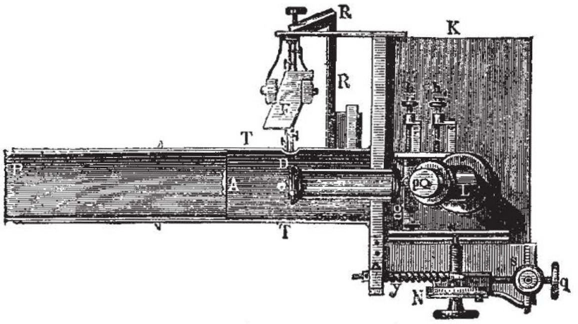

FIG. 27.—Side view of Star Spectroscope, showing the arrangement by which the light from a spark is thrown into the instrument by means of the reflecting prism *e*, by a mirror F.

A fourth element has been discovered by means of the spectroscope by two German chemists, Professors Reich and Richter, who were experimenting on zinc blend, and found two unknown indigo bands in the spectrum, which they successfully traced to the existence of a small quantity of a new metallic element, which has been named Indium.

You all know how important chemical analysis is in thousands of things connected with the arts, manufactures, and commerce, in detecting adulteration for instance, and in these matters the spectroscope gives our chemists a power which was undreamt of a few years ago.

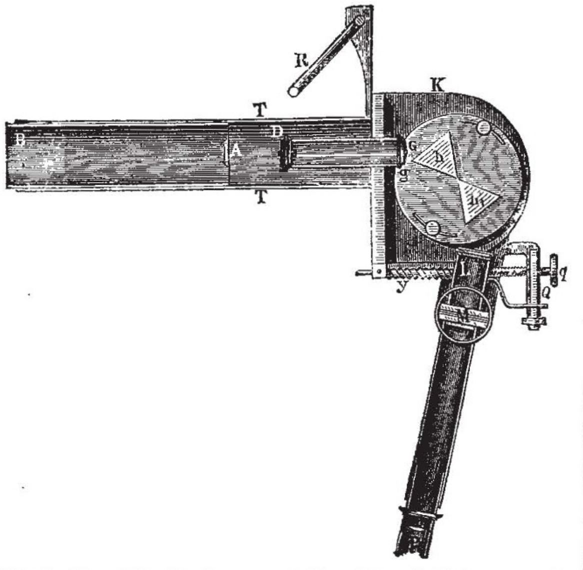

FIG. 28.—Plan of Star Spectroscope. T, Eye-piece end of telescope: B, Interior tube, carrying A, cylindrical lense; D, Slit of spectroscope; G, Collimating lens; *h h*, Prisms; Q, Micrometer.

There is another very beautiful application of the spectroscope which perhaps many of you will say is of more practical importance than those I have already brought to your notice. You know that, in the Bessemer process five tons of cast iron are turned into cast steel in twenty minutes. Now steel is only cast iron minus some carbon. It is clear, therefore, that the process depends upon getting rid of the carbon. How then can the spectroscope aid us in determining the time at which the carbon is got rid of? Nothing is more easy. The heat from the incandescent iron is so intense that the vapour of the different substances mixed with it is visible above the retort in which the metal is placed, and we get, so to speak, an atmosphere of incandescent vapour surrounding the cast iron. When we examine these incandescent vapours by means of a spectroscope, it is found that the spectrum changes very considerably at different times during the combustion of this cast iron. Now it so happens, that the process of conversion is such a delicate one that a mistake of ten seconds either way spoils the whole five tons which are being operated upon. You will see in a moment, therefore, that this is a case in which any rule-of-thumb or very rough method might now and then lead to a mistake; but when the spectrum of these incandescent vapours thrown out by the cast-iron is examined very carefully by means of a spectroscope, it is found that at the first the spectrum of carbon is quite visible, but at the right moment, which has been found by practice, that spectrum disappears, the combustion having been sufficient. All we have to do now, to ensure the charge being properly turned out, is, therefore, by means of the spectroscope, simply to watch certain lines in the spectrum, and when they show signs of disappearance say "Now," and the thing is done without any possibility of error. This is an instance of the practical application of the spectroscope in one direction; now let me give you one in another.

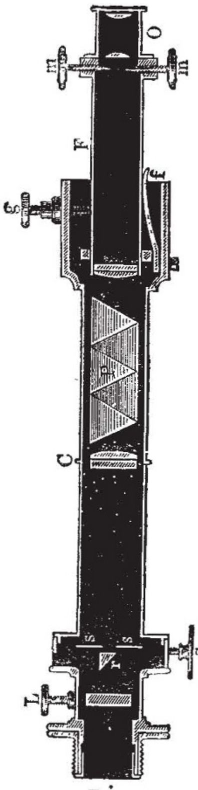

FIG. 29

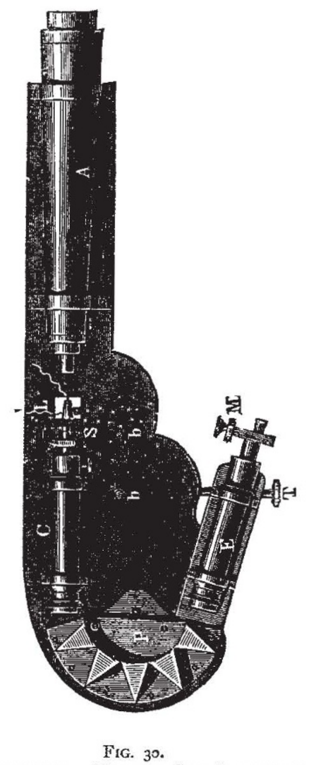

FIG. 30.

FIG 29.—Direct-vision Star Spectroscope.

Fig. 30.—Sun Spectroscope. A, Telescope; S, Slit; P, Prism plate; E, Observing telescope; M, Micrometer.

When Dr. Bence Jones wished to determine some questions connected with chemical circulation, he employed the spectroscope with great success. Many of you, at the first blush, would be inclined to say it was not very likely that the spectroscope would help us here. If it were a question, for instance, of our own chemical circulation, we would not relish the idea of being converted into an incandescent vapour for the pleasure of testing a theory. But, fortunately, there are such things as guinea-pigs, and Dr. Bence Jones, by studying the vapours of the ashes of these animals, has arrived at some results of extreme importance. His *modus operandi* was as follows:—He gave the guinea pigs chloride of lithium, and then the question was to find, by burning the ashes of the different parts of the guinea-pigs, variously removed from the fountain of circulation and from the ordinary ducts of the body, to ascertain how long it took lithium to get absorbed into every part of the body. The most distant part, as far as circulation goes, is the lens of the eye. If, then, we give a guinea-pig chloride of lithium, then kill the guinea-pig, and examine the ash of the eye lens, say three hours after the lithium has been taken into the system, and if we find the lithium line in the spectrum of the ash vapour where no lithium was before, that is to say, if by means of the spectroscope we see that line which we have seen characterises the lithium spectrum, we know that the chemical circulation of the body is such as to take lithium through the body to that particular point of the circulation in that time. In the human subject Dr. Bence Jones has hit upon a very practical method of arriving at something like the same conclusion, by examining the spectra of the ashes of cataracts.

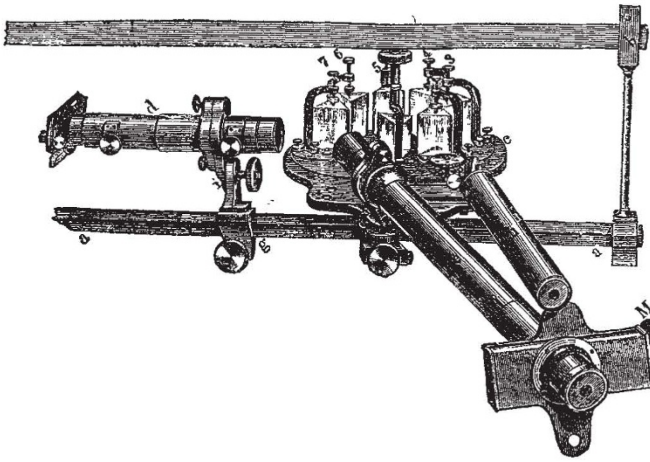

FIG. 31.—Sun Spectroscope. *d*, Collimator; *e*, Observing telescope; *h* and M, Two micrometers; 1, 2, 3, 4, 5, 6, 7, Prisms.

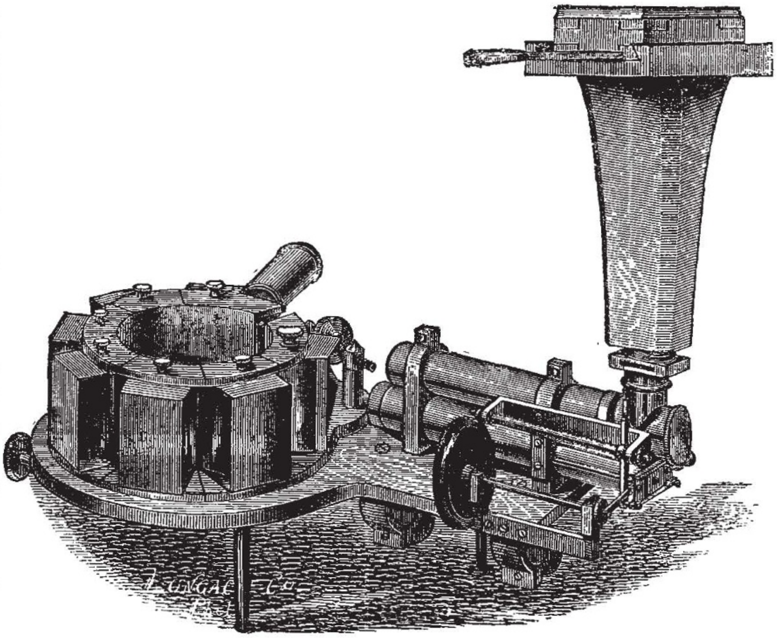

FIG. 32.—Sun Spectroscope arranged for photography.

So far as I have dealt with the applications of the spectroscope, up to the present time, I have dealt in the main with the application to chemistry and to physics, in other words, to the examination of light given out by terrestrial substances; but I must now, with your permission, take you to the skies, reminding you that at present, I am merely dealing with the giving out of light, and with light emitted by celestial objects. We shall afterwards have to deal with the stopping or absorption of light, by vapours and other transparent media when the light passes through them.

I have already referred to the special fittings that were necessary for the application of the spectroscope to the telescope, and I think on carefully looking at the engraving (Figs. 27 & 28) representing a star spectroscope, you will see exactly how the spectroscope is applied to a telescope. We must now go a little more into details. One class of spectroscopes, as applied to telescopes, is arranged for observing the spectra of the stars, nebulæ, &c., and another with a much greater dispersive power for observing the spectrum of the sun.

In both spectroscopes the arrangements employed are similar, and resemble those of the instruments that have been already described. A finder on the side of the large telescope enables the image of the star to be brought on the slit, while, in the case of the sun, its image is received on the slit screen, and any part of the image may be brought on the slit by mere inspection.

The spectroscope is attached to the eye-piece end of the instrument, and the image formed by the telescope is received on the slit plate. Arrangements are necessary in the case of the star spectroscope for widening out the spectrum; this is done by a cylindrical lens (as before explained); and for obtaining a spectrum of comparison, this is done by reflecting into the instrument the light emitted by an electric spark.

In the star spectroscopes, the number of prisms, and the consequent deviation and dispersion, is small. The accompanying woodcuts will make their detailed construction quite clear. In the case of sun spectroscopes, the deviation and dispersion required are large, the deviation amounting to over 300°; that is to say, the ray of light is bent through almost a complete circle; the light from stars is dim, and many prisms cannot be employed to widen out the spectrum, but in the case of the sun, there is light sufficient to give us a bright spectrum after it has been enormously dispersed.

Figs. 31 and 32 show a very powerful spectroscope to be attached to the telescope for observing the spectrum of the sun. One peculiarity of the instrument in Fig. 33 is that the ray of light having passed once through the lower part of the train of prisms, is received by a right-angled prism, which totally reflects the light twice, sending the ray of light back through the upper part of the same prisms, when it is again refracted; we thus have, by using these prisms, the same effect as if thirteen prisms had been employed. The ray of light enters the instrument by the lower tube, and after passing first through the lower half of the prisms, and back through the upper half, is received in the upper tube, and reflected upwards for convenience of observation. These prisms are so arranged, that whatever part of the spectrum is being observed, they are always at the angle of minimum deviation for this part of the spectrum, a very important point, as if this is not attended to the spectrum loses much of its brilliancy and sharpness. This is done either by attaching the prisms to a spring of ebonite or gun metal moving on a fixed point near the first prism of the series, as in the arrangement shown, or each prism may be attached to a radial bar acting on a central pin, as shown in Fig. 33.

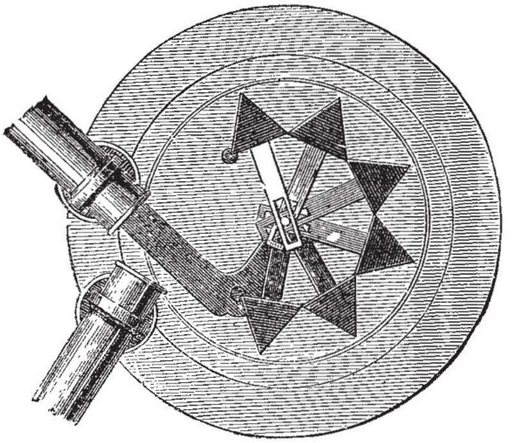

Fig. 33.—Automatic arrangement for securing the minimum deviation of the observed ray.

J. NORMAN LOCKYER

(*To be continued.*)

HUNTERIAN LECTURES BY PROF. FLOWER

LECTURES IV. V. VI.

IT will not be necessary in describing the fossil remains of mammalia to devote any time to the consideration of the Monotremata, for though it might have been supposed that these animals, the Echidna and Duck-bill, on account of their being the lowest in the scale, would have been largely represented in ancient times, evidence to that effect has not been forthcoming. In the post-pliocene of Australia, the lower end of the humerus of a large Echidna, was found by Mr. Krefft, curator of the Museum at Sydney, and that is apparently the only recorded specimen from the class. With regard to marsupial animals the case is very different, and the remains prove that their geographical distribution formerly was not at all what it is now, when they are confined to Australia, the Austro-malay Archipelago, and South America. The family may be classified by the teeth or by the feet. According to the former method the Kangaroos, Phalangers, Koalas, in which there are only two lower incisors, without persistent pulps, form one herbivorous group; the Wombats a second; and those with more than two lower incisors, including the Bandicoots, Dasyures, Thylacine, and Opposums, a third carnivorous section. If the structure of the feet be taken as the main point, the tendency to the reduction of the second and third digits places the Bandicoots with the Kangaroos, instead of with the Dasyures, and does not otherwise modify the arrangement. The at first sight great difference between the molar teeth of the Thylacine and the Kangaroo can be easily bridged over by a comparison of intermediate forms; looking for instance at an upper molar in the latter, its crushing surface presents two broad ridges, with an intermediate depression, in which there is an oblique groove. In the Thylacine there is a central large, and two lateral smaller tubercles, with a band connecting the medium with one of them. There is also a small posterior and two very small anterior tubercles in the cingulum. In Perameles the molar presents two rows in a double crescent, in front of which are four minute processes, which represent those of the cingulum of the Thylacine, the crescents being representatives of the big tubercles. In the Kangaroo Rats the tubercles alone remain, and in the Kangaroo these blend to form the ridges.

Respecting the fossil forms, those from the Purbeck beds have been thoroughly worked out by Prof. Owen. With the exception of *Plagiaulax* they belong to the polyprotodont division, and nearly all have more than seven teeth of the molar series, *Triconodon* and *Triacanthodon* being the exceptions, they also being peculiar and differing from all existing Marsupials in having four premolars and three molars. There is no evidence to show whether there was any succession of the teeth. *Plagiaulax* has been the subject of one of the most important controversies in connection with palæontology, between Prof. Owen and the late Dr. Falconer, the former maintaining that it was carnivorous, eating the lizards found with it; Dr. Falconer that it was herbivorous and allied to *Hypsiprymnus*. The fact of its having only two lower incisors, and that the molars are hypsiprymnine in form tends to show that it must have had some relation to the herbivorous group, and shows that at so ancient a date the family had already divided in the manner that we now find it.

The tertiary Marsupialia must next be considered. In the Eocene gypsum of Montmartre several small skeletons have been found, clearly referable to the Opossums, and with a similar dentition, from which Cuvier was able to classify them correctly and predict the existence of marsupial bones in the uncovered skeletons. From Auvergne three similar miocene species have been described, and in England Mr. Charlesworth has, on undoubtedly insufficient evidence, referred a premolar to the same genus, Didelphys. The Yale College expedition have obtained, among the large number of bones that they have collected, some which Prof. Marsh thinks are Marsupial. In the Pliocene there have not been any fossil remains of this sub-class yet obtained, but many in the Quaternary period. In the Brazilian caves Opossums have been found in abundance, and in the Wellington Valley and many other parts of Australia extremely interesting forms have been obtained, which must be referred to more fully. Prof. Owen has studied them in great detail. The remains may be divided into two divisions; (1), those allied to existing genera; and (2), those not now represented. With regard to the former it is interesting to observe that the Thylacine and Ursine Dasyure, now restricted to Tasmania, at one time abounded on the mainland. There are also remains of enormous Wombats and