SPECTRUM ANALYSIS AND ITS APPLICATION TO SCIENCE.

By Francis Abbott, F.R.S.

At the monthly meeting in March, 1863, I brought before the Members of the Society some notes relative to the researches and early investigations into the phenomena and history of prismatic analysis.

At that time the researches of Professor Kirchoff, and Bunsen's appliances for the examination of colored flames, were but little known. Spectroscopes were scarce, and had not been introduced into the colony, consequently the only way of illustrating the paper was by means of colored drawings and some scientific apparatus. Many important discoveries have, however, been made since that period, especially from the results of Spectrum Analysis applied to the heavenly bodies, some of which will be rendered more apparent by the few following preparatory notes on the subject:—

It is well known that the laws of radiant light and heat are not only very similar but that these phenomena themselves are in all probability due to the same physical cause. "This analogy," says Balfour Stewart, "between light and heat as regards reflection, refraction, absorption, and probably polarization, will tend to show that radiant light and heat are only variations of the same physical agent, and also that when the spectrum of a luminous object has been obtained the separation of the different rays from each other is physicaly complete." In any region, therefore, of the visible spectrum the illuminating and heating effects are caused by precisely the same rays. If, for instance, we take the region of the spectrum near the violet, or most refrangible extremity, we find that luminous and chemical effects are produced, and in both cases the same rays are the active agents.

The solar spectrum has the property of being intersected by a series of dark lines, which are of great service in showing that there is only one active agent at one part of the spectrum, for towards the left extremity, or the red end of the spectrum, there is at the same time a heating and illuminating effect. These different rays possess distinctly heating, luminous, and chemical properties; there is, however, a great difference between the first of these and the two latter, "for the heating effect of a ray may be made the physical measure of the power which this portion of the spectrum possesses."

When light which has emanated from different sources is decomposed by a prism, the spectra which are obtained may differ in several important respects from each other, but all of them can be conveniently arranged in three general groups.

The special character which distinguishes spectra of the *first order* is that the continuity of the colored band is unbroken either by dark or bright lines. We learn from such a spectrum that the light has been emitted by an opaque body, and most probably by matter in a solid or liquid state. A spectrum of this order gives no knowledge of the chemical nature of the incandescent body from which the light comes.

Spectra of the *second order* are very different. These consist of colored lines of light, separated from each other. From such a spectrum we learn that the luminous matter from which the light has come is in the state of *gas*. Every compound body that can become luminous in the gaseous state without suffering decomposition is distinguished by a group of lines peculiar to itself. Substances *when in the state of gas* may be distinguished from each other by their spectra, providing the lines characteristic of the different terrestrial substances are known. The discoveries effected by Mr. Huggins have shewn that many of the Nebulæ are of gaseous composition, presenting the spectrum of bright lines separated by dark spaces.

The *third order* consists of the spectra of incandescent solid or liquid bodies, in which the continuity of the colored light is broken by dark lines. These dark spaces are not produced by the source of the light; they are produced by vapours through which the light has passed on its way, and which have robbed the light by absorption of certain definite colors, or rates of vibration; such spectra are formed by the Sun and Stars.

The spectra obtained from the Moon and Planets are unlike those produced by the Stars and Nebulæ, these latter not being original sources of light, but shining by reflection only; their spectra resemble, therefore, a modification of the solar spectrum.

Circumstances frequently unite in rendering investigations of this nature very difficult. On but few of those nights when the stars shine brilliantly is the air sufficiently steady for such very delicate observations. The light of the Stars is also very feeble, and requires a large instrument with an object glass of not less than eight inches aperture to gather up and concentrate to a focus the light from so small an object.

Another inconvenience arises from the apparent motion of the Stars caused by the rotation of the Earth. This difficulty has been overcome by the application of clock work, by which the telescope and observer are moved in a direction opposite to that of the Earth, by which means the object is kept within the focus of the instrument. In practice, however, it is found not easy to retain the image of a Star steady for any length of time exactly within a slit, the jaws of which are only 1-300th of an inch apart.

These difficulties being overcome, the light produced by a terrestrial substance is compared with the Stellar Spectrum by means of a prism fixed over one half of the slit, which receives the light reflected into it by a movable mirror that faces a clamp of ebonite, provided with forceps to hold the fragments of metals employed. These metals are rendered luminous in the state of gas, by the intense heat of sparks produced from a powerful induction coil. The light from these sparks is reflected into the instrument by means of the mirror, and a small prism being placed in connection with the larger one, which receives the light from the Star, the two spectra are visible in juxtaposition, by means of a small telescope; and thus the coincidence and relative position of the bright lines in the spectrum of the Star can be accurately determined by the bright lines in the metallic spectrum.

The spectroscope, as an instrument of research applied to scientific discovery, had never a more fitting subject to operate upon than that for the investigation of which the "Rigid Spectroscope" was contrived by J. P. Gassiot, V.P.R.S., and manufactured by Mr. Browning.

It is customary to speak of light, heat, electricity, &c., as "imponderable agents," or as gravity, a property manifested under certain conditions, Mr. Balfour Stewart, and Professor Tait, of Edinburgh, in technical language employed by the former, state: "That to this time it has been assumed, without proof, that the change in the co-efficient of terrestrial gravity does not in itself alter any other co-efficient of a body, and if a reason be asked none can be given, since gravity is a force of nature, of which men of science are confessedly ignorant." Now, if gravitation acts upon light so as to have a share in determining the position of any rays emerging from a prism, and forming a spectrum, a considerable change in the position of such a prism and of such light rays, involving a change in the force of gravitation, might cause a dark line in the spectrum to take a new position, more or less differing from that which it first assumed. The construction of this "Rigid Spectroscope," therefore, was to ascertain whether the position of the well-defined lines of a spectrum is constant, while the co-efficient of terrestrial gravity under which the observations are taken is made to vary.

The difficulties of making such a Spectroscope were very great, but they have been overcome, and a series of trials in Mr. Browning's workshop at Kew, and in the apartments of the Royal Society, have shewn that the variation of the D line is quite infinitesimal, in spite of great changes of temperature, and the removal of the instrument from place to place.*

Great interest has of late years been attached to the composition of Meteors, shooting Stars, and Bolides, to learn something of which, Mr. Alexander Herschel has constructed a direct-vision Spectroscope, fitted up with peculiar prisms for binocular arrangement, having a wide field of view and great power. This instrument, like the former, presented considerable difficulties of optical construction, which have been overcome by Mr. Browning.

Observers furnished with a Binocular Spectroscope may direct it like an opera-glass to that portion of the sky where the Meteors are expected to fall vertically towards the Earth, near (but not too near) the radiant point, where their course is foreshortened, and their apparent motion comparatively slow. As Meteors and shooting Stars make lines of light in the sky, each will give one or more lines of light in the Spectroscope. If, for example, we had a *Sodium* Meteor, it would give a *yellow* line in the sky, and a yellow line occupying the place of the Sodium line in the Spectroscope. If *Silver* were present, together with Sodium, the Meteor train would have a greenish tinge, and three lines would appear in the Spectroscope; viz., *yellow*, *green*, and *blue*. The spectral examination of the August Meteors has brought to light the fact of the existence

* Since these remarks were made on the Rigid Spectroscope, it has come to my knowledge that the instrument has been put on board of H.M. Ship Nassau, in charge of Captain Mayne, who was preparing to make a survey of the Straits of Magellan. A lengthy correspondence with some results has been received by J. P. Gassiot, Esqr., from Captain Mayne, which was placed in the hands of Pro. Stokes, and Mr. B. Stewart, from which it appears that the result at present influencing the variation of gravity does not exceed in passing from Lat. 45° to the Equator, a change of refraction for the yellow of the spectrum equal to about three-fourths of the interval of the D-lines, but more observations are required on the ship's return before it can be asserted that this apparent change is not due to known causes.

of an extraordinary quantity of the vapour of Sodium in their composition.

One point of importance to be ascertained by means of the "Meteor Spectroscope" is whether shooting Stars and their luminous trains, are composed of porous or of solid matter, and from Spectrum Analysis of the August Meteors the probability is that their composition is a mineral substance in which sodium is one of the principal ingredients.

From the study of mineral matter in a state of incandescent vapour, Spectrum Analysis has become of the greatest importance. Much is also learnt by observations on the light transmitted by or reflected from solutions of colored substances, however small the proportion in which they may be present, and in this way the Spectroscope has been very successfully applied to the Microscope. In examining the solutions prepared for this part of the subject there will be seen on the stage of the Microscope what have been named Fraunhofer's dark lines, which have been made by Professor Kirchoff the key by which this kind of writing can be deciphered and read.

When a ray of light falls upon a glass prism two different actions take place ; first the ray is refracted or bent out of its course, secondly, it is opened or spread out like a fan. This last action is called dispersion ; the dispersion of any part of the spectrum is proportional to the angular interval between two rays of nearly equal refrangibility ; both these actions depend on the substance employed in the formation of the prism. The size and character of a Spectroscope, the quality and number of prisms required, with such refracting angles as will produce the greatest dispersion with the least loss of light, should be regulated by the work required of it.

For the detection of metals, the spaces, and bands by which their presence is indicated, are conspicuously shown by an instrument that will display the chief lines of the Solar Spectrum, but there are many thousand lines discernible with more powerful apparatus, and many lines that appear single under ordinary circumstances,are foundto be double ormultiple when examined by superior means.

As a means of research, the application of Spectrum Analysis to the Microscope has not yet been attended with results of so decided a character as the study of mineral matter in a state of incandescence, although by such application we can detect and measure very minute quantities, and also compare the spectra of two solutions together.

It is much more difficult to learn what is and what is not characteristic in objects prepared for examination in this kind of analysis. For example, the exact position of the dark absorption bands in the spectrum obtained from blood is of an important character; it requires but little dispersion, and it is necessary to use the Micrometer for measurements, as well as suitable tests for proof. A solution of *Cudbear* in dilute alcohol yields two very faint bands in much the same place as those of fresh blood, but on adding ammonia one band becomes very dark and distinct, and the lower band disappears altogether. The addition of ammonia to a solution of fresh blood produces no such changes. If ammonia is added to a solution of cochineal, two absorption bands are produced in much the same position as those of fresh blood, and without care they might be confounded.

There are many objects like the foregoing which require careful and proper appliances; there are also many others of a much more characteristic kind. A striking spectrum is produced by a very dilute solution of *Permanganate* of *Potash,* which gives five well marked absorptions bands at about equal intervals in the green, and one or more in the blues. *Aniline Red*, *Madder*, coloured crystals, and many other substances, make easy and suitable objects for the Microscope, if the solutions are not made too strong, so as to destroy the delicate absorption bands. Sometimes these absorption bands are broad and indistinct, but in other cases narrow and well defined, and they are then much more characteristic.

The best known object for testing fine definition is a pale blue solution of Chloride of Cobalt in a concentrated solution of Chloride of Calcium. If the two lines are seen in the orange the definition must be very satisfactory.

To show the effects produced by means of Spectrum Analysis under the Microscope I have prepared very weak solutions of the following substances, viz.:—Permanganate of Potash, Aneline Red, Madder, and Cochineal; also fresh blood largely diluted. It must, however, be understood that a casual exhibition of these spectra is one thing and a scientific enquiry is another, for every part of the spectrum differs from the adjacent parts in refrangibility, and delicate bands can only be brought out by accurately focussing their own parts. It is, therefore, necessary to close the shutters in the Spectroscopes over the slit on the remainder of the object, by means of the two levers provided for the purpose, leaving only that portion of the spectrum visible which is under examination.

It will therefore appear clear that time will not admit of entering into these details, as the object intended this evening was more to explain and illustrate the principle adopted for ascertaining the characteristic spectra produced from the luminous vapours given off by the combustion of the following metallic substances. It will be remembered, however, that some of the coloured lines produced by these metallic vapours, although very characteristic and decided, are but of short duration.

1st. *Sodium.*—The spectrum-reaction of *Sodium* produces only one yellow line which is coincident with Fraunhofer's dark solar line D, for if the *soda* and the *solar* spectra were to fall one over the other the *yellow soda* line would exactly cover the dark solar line D. This is important, as it enables us to draw the conclusion respecting the presence of soda in the *Sun's* atmosphere.

2nd. *Lithium.*—The spectrum produced by this metal is very beautiful and quite characteristic. It consists of one intensely brilliant crimson line, and one less distinct orange line.

3rd. *Chlorate* of *Potassium.*—All compounds of this substance give a widely extended continuous spectrum, which contains only two characteristic lines, one in the outermost red, approaching the ultra-red rays, which coincides with the dark line A. of the *Solar* Spectrum, and a second line situated at the extreme end of the violet rays.

4th. *Nitrate* of *Strontia.*—The spectrum produced by *Strontia* is especially characterized by the absence of green bands. There are eight lines in this spectrum which are remarkable, namely, six red, one orange, and one blue. These *Strontia* bands are important both as regards their position and intensity.

5th. *Chloride of Barium.*—The spectrum of the compounds of *Barium* is the most complicated of the spectra of the alkalis. It is at once distinguished from all the others by two green lines, which are by far the most distinct, appearing the first, and continuing during the whole of the reaction.

6th. *Chloride of Calcium.*—This substance becomes gas at the temperature of flame, and gives a characteristic spectrum, which is distinguished from the foregoing spectra by a very bright green line and one intensely bright orange line, lying very near the red end of the spectrum.

There are other substances I propose to submit if time allows, viz., the metal *Thalium*, which produces the beautiful intense green *Thalium* line, very near the solar line D; Sulphur, which is various; and a mixture of the foregoing substances, which gives the characteristic lines of each in the spectrum.

In conclusion, it may be asked what new knowledge have we gained by prismatic analysis? We have seen that the Stars contain material elements and have a structure analagous to that of the Sun, also that their colours originate in the chemical constitution of the atmosphere surrounding them. The variable Star in Corona appears to show that great physical changes are in operation.* That the material of Comets is similar to the matter of the Gaseous Nebulæ, and may be identical. That Meteors, Bolides, and shooting Stars are of mineral composition. That our investigations of the universe are undergoing important changes, and that we require to wait patiently for more facts from the obvious teachings presented to us by new observations, doubting not that for wise purposes the Great Creator superintends the whole.

* Mr. Huggins and Dr. Miller, in analysing this Star, found its light to form a spectrum unlike any other celestial body that has been examined. It is compound, and emanates from two different sources, each light forming its own spectrum, one of which, in the instrument, appears to be superposed over the other. One of these is formed by 4 bright lines. The other is analagous to the spectra of the Sun and Stars. It is known by the position of the bright lines in the spectrum that one of these luminous gases is *hydrogen*, and this taken in connexion with other circumstances together with the sudden outburst of the Star, has suggested the probability of the Star becoming suddenly enwrapt in a flame of burning *hydrogen*. This Star is No. 2,765 of Argelander's Zone, + 26°, and at the time of Argelander's sweep it was below the 9th magnitude.

2. Mr. Baxendell has supplied the following table of magnitudes :—

1868.	May 15,	at	12h. 0m.	G. M. T.,	T. Coronæ	=	3.6 or 3.7	magnitude.
	,, 16	,,	10h. 30m.	,,	,,	=	4.2	,,
	,, 17	,,	11h. 0m.	,,	,,	=	4.9	,,
	,, 18	,,	12h. 30m.	,,	,,	=	5.3	,,
	,, 19	,,	12h. 15m.	,,	,,	=	5.7	,,
	,, 20	,,	12h. 13m.	,,	,,	=	6.2	,,
	,, 21	,,	12h. 0m.	,,	,,	=	7.3	,,
	,, 22	,,	11h. 15m.	,,	,,	=	7.7	,,
	,, 23	,,	10h. 30m.	,,	,,	=	7.9	,,
	,, 24	,,	10h. 30m.	,,	,,	=	8.1	,,

3. If we take in the objects from the Chinese Catalogue of Ma-Tuan-Lin, there are recorded about 20 of these remarkable Stars during the last two thousand years.