

ATOMS AND MOLECULES SPECTROSCOPICALLY CONSIDERED *

II.

I now pass on to another part of my subject.

7. When low temperatures are employed it is generally acknowledged that there is an important difference in kind between the spectra of metals and those of metalloids, taken as a whole.†

Spectroscopically it is more easy to define the difference between these two great classes of metals than the chemists among you would imagine. I will ask you to take the spectrum of the third class of stars as being as good a representation of the spectrum of a metalloid as anything I can place before you. It

is rhythmic, the other two are not. It is a "channelled space" spectrum.* That defines a metalloid spectrum; and a similar spectrum in the case of hydrogen is referred by Angström, Stewart, Schuster, and others to an impurity. I have before referred to temperature and told you that the temperature of a Bunsen burner is enough to set an atom of sodium free from its combination with chlorine and make its vapour give us a bright line. I have told you we cannot do this in the case of iron and other substances. We may say then that we have there a first stage of temperature. Many monad metals give us their line spectra at a low degree of heat. Take some dyad metals such as zinc and cadmium; this first stage of temperature will only make them red or white hot, a much higher temperature is required to drive them into vapour. We get the line spectrum from sodium; do

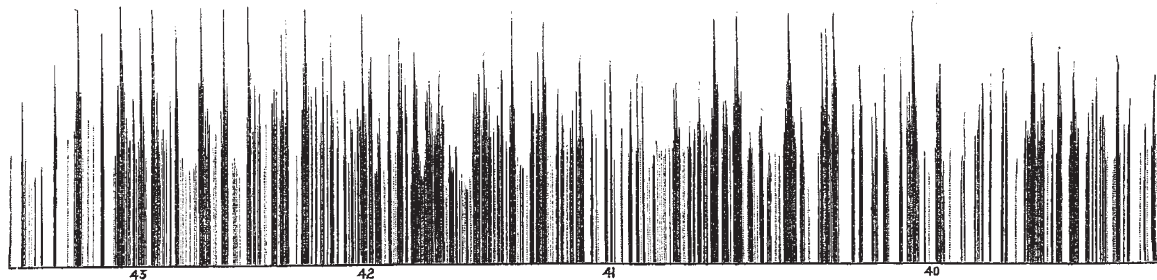


FIG. 3.—Copy of a photograph of the long and short lines of iron between wave-lengths 4,600 and 4,300.

we get that from cadmium when we have melted cadmium? We do not. That is an excessively important point. The first stage of temperature, which gives you a line spectrum in the case of sodium, is powerless to give you such a spectrum in the case of cadmium.

A second stage of heat at least is therefore required to get a line spectrum. If I take sulphur, dealing with it by means of absorption, and heat it, I get a continuous spectrum at the first stage. I increase the heat to the second stage, what do I get then? A line spectrum, as I do in the case of sodium? No! A spectrum like that of the star in the constellation Hercules, not a line spectrum at all. I apply still a higher, a third, stage of temperature and then I get a line spectrum. In the case of the metalloids we have thus three stages of heat with three spectra. If there is such a thing as a particle at all, are we not justified in asking whether there is not some difference between the "particular" arrangements of the metalloids, from those of the metals? and some connection between temperature and the "atomic weights" of the chemist?

Before I go further I will throw these results into a tabular form, which will show you that through these various heat stages in the case of metals like sodium there is a great preponderance of line spectrum, and in the case of metalloids like sulphur there is a great preponderance of channelled space spectrum.‡

	Na.	Cd.	S.
Fifth stage—spark	line spectrum	line	line
Fourth stage—arc	line	line	channelled space
Third stage—white heat	line	line (?)	channelled space
Second stage—bright red heat	line	continuous absorption in the blue	channelled space
First stage of heat—dull red heat	line	continuous spectrum	continuous absorption in the blue

8. I next state that *A compound particle—that is a particle consisting of two distinct elements—has a vibration which is as peculiar to itself as the vibration of a particle of an element is peculiar to itself.*

* Continued from p. 87.

† Since this lecture was delivered Prof. Roscoe has established the existence of new spectra of sodium and potassium closely resembling the well-known ones of the metalloids.

‡ Since this lecture was delivered I have carried this branch of the research much further, and it seems one well deserving of the attention of physicists and chemists, as when it comes to be acknowledged that different classes of spectra do truly represent different "particular" aggregations, the contrast between the extremes of metals and metalloids will be beyond question. The result marked thus ¶ I have added from later work.—J. N. L.

Thus the salts of strontium have each a distinct spectrum. Take the particle of N_2O_4 . The absorption spectrum of this gas you now see on the screen. This particle has a vibration quite of its own. Now it is a gas which it is perfectly easy to dissociate. It is easy to turn it from N_2O_4 to NO_2 . We introduce a new spectrum. These facts—and they might easily be multiplied—show then that a compound particle is a perfectly distinct physical thing, with vibrations, rotations, and free paths of its own. There is no apparent connection between the vibrations of a compound particle and those of any of the substances which make up that compound particle.

9. I now come to another important point: *On the whole certain kinds of particles affect certain parts of the spectrum.* Take the bright lines of the metals; if you were to mix together all the known metals in the sun, make a compound which should consist of all of them, put it into the lower pole of an electric lamp and photograph the spectrum, then you would find the majority of the lines would be in the violet end of the spectrum, scarcely any in the red end. That is the reason why the spectrum of the sun, which contains so many of the metals, is so complicated in the violet. If you combine a metal and a metalloid, you will find, in many cases at all events, that the vibrations will lie in the red end of the spectrum; you will also find that there is a connection between the atomic weight of the metalloids and the region of the spectrum in which their lines appear under similar conditions.

You have, in fact, simple particles and short waves, compound particles and long waves. Nor is this all. In many cases we find both ends of the spectrum, and in many cases the more refrangible end only, blocked by continuous absorption. This occurs so often in absorption spectra that one is led to suspect that it is due to some arrangement of particles.

10. Here is another proposition: *In the case of metalloids, and compound gases containing them, the spectrum to a large extent depends upon the thickness of the vapour through which the light passes, and often, if not invariably, the absorption increases towards the red end as the thickness is increased.*

Here is one of the points of the most extreme theoretical importance, and one about which least is known. There is a statement in Prof. Maxwell's book, that if you take a metallic vapour and employ a great thickness of it, you will get from it the same spectrum as you would from a small thickness of great density. This is Prof. Maxwell's statement; I venture to think that this is somewhat doubtful, for in questions of thickness the spectroscopist can offer the physicist a million of miles or a millimetre to work with, and one would think that such a difference should be enough. If I had a tube with a bore of the size of the lead in this pencil, and had some hydro-

* By an oversight last week the illustration here referred to was inserted instead of the present one.—J. N. L.

gen gas rendered incandescent, you would see a line of a certain thickness, with a certain pressure. Looking through the sun's coronal atmosphere in an eclipse, you pierce seven or eight hundred thousand miles of hydrogen gas. The thickness of the lines is the same. Various thicknesses of sodium vapour do not alter the thickness of the lines. But if we pass from metals to the metalloids, then certainly one is prepared to go on with the professor to any extent. I can show you how true his statement is photographically. There is considerable interest attached to the question whether there is or is not any chlorine in the sun's outer atmosphere. I have endeavoured to settle this question, contrasting the absorption chlorine spectrum with the solar spectrum; different thicknesses of chlorine have been employed. It seems that, if we take the metalloids, the absorption of a small thickness often takes place in the violet portion of the spectrum.

Now can these results be harmonised? Here I acknowledge we tread on very difficult ground, and with our present knowledge it would be perhaps best to say nothing; but I am not sure that this would not be scientific cowardice, so I will ask, under all reserve, whether the following explanation may not be a probable one? With metallic vapours the lines, though not widened as they are widened by great density, are certainly darkened, but all the lines are not visible—only the longest, generally. Now if we assume that the channelled space spectrum of the metalloids is really, even where it appears continuous, built up of lines,* then the darkening of these lines by greater thickness will not only make those darker that we see with a small thickness but bring others into visibility; and if this goes on till we have a very great thickness we may have an immense difference in the appearance of the spectrum.

11. *Some of the vibrations are very closely connected with others, as evidenced by repetitions of similar groups of lines in different parts of the spectrum.*

Here we are brought face to face with a revelation of the vibrations of particles, which, if I am not mistaken, will be made much of by the mathematical physicist in the future.

I will content myself by giving two or three striking instances, first noticed by Mascart. You will see that the longest line is at work in all of these.

In sodium we may say that the longest line is double; I refer to D' and D". All the lines are double.

In magnesium the longest line is a triple combination. This is repeated exactly in the violet.

In manganese we may almost say that the same thing happens, but the phenomenon is much more absolute in the case of those particles such as sodium and magnesium, which, on other grounds, I suspect to be of the simplest structure.

12. *Our knowledge of the vibrations of particles will be incomplete until the vibration is known from the extreme violet (invisible) to the extreme red (invisible). In the meantime great help may be got from inferences, and, in the case of metalloids at low temperatures, from the position of their continuous absorption; and it is a question whether light may not be thus thrown upon the opacity of some solid substances and the transparency of others.*

I think it not too much to say already, that in the case of some gases and vapours which are apparently transparent it is as certain in some cases that their absorption is in the ultra red, as it is certain that in the case of others the absorption is in the ultra violet. And further it is probable that this absorption is of the continuous or channelled space kind—in other words that no gas is "atomic" in the chemist's sense.

13. *From the fact that we have lines in the spectra of compound gases, it would be hazardous to affirm that the aggregate, which, with the highest dissociating power we can employ, gives us line spectra, could not be broken up if a still higher dissociating power could be employed.*

This proposition has a bearing on the celestial rather than on the terrestrial side of the inquiry, and as my time is drawing to a close I will refrain from enlarging upon it.

There is another branch of the research I am anxious to bring to your notice. I can do this better by experiment than by a simple statement.

The substance which you see here is a piece of gold leaf; it is yellow, as you know, but gold is sometimes blue and sometimes red. It must be perfectly clear to you, that if particles vibrate the colours of substances must have something to do with the vibrations. If the colours have anything to do with the particles it must be with their vibrations. Now as the spectrum in the

main consists of red, yellow, and blue, the red and the blue rays are doing something in a substance which only transmits or reflects the yellow light; put the gold leaf in front of the lime light, you will see whether the yellow light does or does not suffer any change. The yellow has disappeared; you have a green colour; the red and blue are absent. The gold leaf is of excessive thickness. What would happen could I make it thinner? Its colour would become more violet. This I have proved by using aqua regia. But here is a solution of fine gold, which lets the red light through. Its particles are doing something with the blue vibrations, or *vice versa*. Now what is the difference—the "particular" difference between the gold in this solution which is red, and that which is yellow by reflected, and green or violet by transmitted light? It is a question worthy of much study, especially in connection with my ninth proposition. Here are some more experiments. Here is some chloride of cobalt, which is blue. I will put it in this test-tube, to which I will now add water. You see it turns red. I content myself by asking why it turns red? We take some chloride of nickel, which is yellow, and put it into another test-tube: we add water, and I think you will soon see it turns green. First question—Why this change? Second question—Has the green colour of this solution anything to do with the red colour of the solution of gold?

I ask these questions because I believe the spectroscope will in time answer them.

I hope you will acknowledge that the spectroscope has to a great extent vindicated the theory stated by Prof. Maxwell. The question is, Has it taken us further? Perhaps not yet, but I think it will be found that what chemists picture to themselves as the atom, as contradistinguished from what they weigh, and physicists the molecule, is that particular atom, molecule, particle, or whatever name you may choose to call it, which with high-tension electricity gives us a spectrum of lines. You recollect that I said that in many of the monad metals it was obtained in the first stage of temperature; in the case of the dyads and metalloids with higher stages. If the true atom be that which gives a line spectrum, many anomalies will fall to the ground. These are questions the spectroscope raises. If you allow that in the line spectrum an atom is at work, in channelled spectra and continuous spectra molecular aggregations, you will see at once that Prof. Maxwell and others will be able to get a much sharper definition of atom and molecule than they have now; and though atoms are little things, you know they lie at the root of everything, and time spent in investigating them will not be lost.

J. NORMAN LOCKYER

A BOTANICO-GEOLOGICAL EXCURSION INTO THE GRAMPIANS

THE Scottish Alpine Botanical Club is wont to hold a spring meeting for mingled plant-hunting and conviviality in some Highland district where the Alpine flora can be reached at not too great a distance from oat-cakes and whiskey. The Geological class in the University of Edinburgh is in the practice of terminating its labours for the winter by taking an excursion of a week's duration to some part of the country where professor and students can find interesting rocks, with enough of food (such as it may be) to eat, and of beds, or shake-downs, to sleep on. This year the two bodies, drawn together perhaps as much by animal spirits as by scientific enthusiasm, coalesced and held a conjoint gathering at Clova—a lonely hamlet on the Forfarshire Grampians, well known to botanists for the richness of its Alpine flora, and to geologists for its glacier relics and its ancient metamorphic rocks. The following notes by the respective leaders of the plant-seekers and the rock-hunters were communicated to the Edinburgh Botanical Society on the 14th ult. :—

1. *Botanical Notes by Prof. Balfour.*—On Friday, April 24, the botanists visited the lower part of Glen Fee and the western side of Glen Dole. They specially examined the rocks in Glen Fee, where *Oxytropis campestris* grows and along with the plant took specimens of the rock for the determination of the geologists. They also visited

* Thalen's beautiful researches on the spectrum of iodine quite bear out this view.