

THE METHODS OF INORGANIC EVOLUTION.

IN the study of the facts of inorganic evolution presented to us by stellar spectra, there is one point of paramount importance to be inquired into. In the problems of inorganic evolution which we have now to face, it is sufficiently obvious that we have to deal with a continuously increasing complexity of chemical forms, precisely as in organic evolution the biologist has had to deal, and has dealt successfully with, a like increase of complexity of organic forms.

How has this inorganic complexity been brought about? In the case of known compound bodies an easy answer is given by analysis. Chloride of sodium, for instance, is formed by the combination of chlorine and sodium. But when we wish to deal with the formation of the so-called "elements" themselves, no such easy solution of the problem is open to us.

If in order to investigate this problem we take the analogy furnished by compound bodies as our guide, we should say that the molecules of the elements themselves were produced by the combination of unlike forms.

But as a matter of fact, this method of producing complexity is not the only one known to chemists. There are bodies of the same percentage composition which differ in molecular weight; the methane series of hydrocarbons is a case in point; the higher molecular weights or greater complexes are produced by additions of the unit $C.H_2$, so that these higher complexes are produced by the combination of similar lower complexes. This process is termed polymerisation.

We are then familiar with two methods of increasing complexity, which we may represent by $a + a$ (polymerisation) and $x + y$ (combination), producing a form A.

This, then, is the problem from the purely chemical side. On which of these methods have the elements themselves been formed, now that we are justified in considering them as compound bodies? I suppose that chemists when hypothetically considering the possible dissociation of the chemical elements would favour the view of depolymerisation; that is, the breaking up of a substance A into finer forms (a) weighed by $A/2$ (or $A/3$), rather than a simplification of A into x and y .

The method of attacking this problem from the chemical point of view in the first instance, must be a somewhat indirect one.

The Stars and the Periodic Law.

In a recent lecture I referred to the hypothesis put forward by Newlands, Mendeléef and others in relation to the so-called "periodic law," which law indicates that certain chemical characteristics of the elements are related to their atomic weights. I further showed that the order of the appearance of the various chemical substances in the stars of decreasing temperatures did not appear to be on all-fours with the requirements of the periodic law.

It will be well to study this question with a view of discussing it more fully in the light of all the facts known to us, among which the stellar evidence and that afforded by the study of series are, I think, of especial importance, since it may be said that we are now absolutely justified in holding the view that of the lines which make their appearance in the spectra of chemical substances when exposed to relatively high temperatures, a varying proportion is produced by the constituents of the substance, whether it be a compound like the chloride of magnesium, to take an instance, or of magnesium itself.

Now the periodic law based upon atomic weights deals with each "element" as it exists at a temperature at which the chemist can handle it; that is, if it be a

question, say of magnesium, the chloride or some other compound of the metal must have been broken up, and the chlorine entirely got rid of before the pure magnesium is there to handle, and of this pure magnesium the atomic weight is found and, having also regard to its chemical characteristics, its position in the periodic system determined.

But if the magnesium be itself compound, the position thus assigned for the element is certain not to tally with the stellar evidence if the temperature of the star from which information relating to it is obtained is high enough to continue the work of dissociation; that is to break up magnesium itself into its constituents as certainly as the chloride of magnesium was broken up in the laboratory in the first instance.

It is now known that dealing with this very substance magnesium, high electric tension brings us in presence of a spectrum which consists of at least two sets of lines, numerous ones seen also at the temperature of the arc, and a very restricted number which make their appearance in the spark.

If this be the work of dissociation—and, as I have shown elsewhere, the proofs are overwhelming—the "atomic weight" of the particle, molecule or mass, call it what you will, which produces the restricted number of lines—the enhanced lines—must be less than that of the magnesium by the breaking up of which it is brought into a separate existence.

And now comes the chief point in relation to the periodic law. *Seeing that the smaller masses which produce the enhanced lines have not been yet isolated, their "atomic" weights and their chemical characteristics have not been determined, and so of course their places in the periodic table cannot be indicated as it at present exists.*

My contention, therefore, is that some, at all events, of the apparent discrepancies between the stellar evidence and the "periodic" hypothesis arise from this cause.

The magnesium, and I will now add calcium, which the chemist studies at relatively low temperatures have atomic weights of 24 and 40 respectively, and the stellar evidence would be in harmony with the periodic law if magnesium (24) made its appearance after sodium (23), and calcium (40) after chlorine (39), and generally each substance should make its appearance after all other substances of lower atomic weight than itself.

But, and again for the sake of simplicity I shall confine myself to magnesium and calcium for the moment, in the stars we find lines in the high temperature spectrum of magnesium and calcium appearing before known lines in the spectrum of oxygen which has an atomic weight of 16.

How are these results to be reconciled? I suggest that the explanation is that the substances revealed by the enhanced lines of magnesium and calcium and noted in the hottest stars have lower atomic weights (smaller masses) than the oxygen of the periodic table.

Let us next, then, see what these atomic weights may possibly be. Assuming $A/2$ the atomic weight of proto-magnesium would be $24/2 = 12$; of proto-calcium $40/2 = 20$, supposing only one depolymerisation has taken place. If we assume two, we get 6 and 10 as the "atomic" weights of the simpler forms of magnesium and calcium which make their appearance in the hottest stars.

In this way we can explain the appearance of those finer forms of magnesium and calcium before oxygen, with a small number of depolymerisations, and the stellar record of the order of atomic weights would be the same:

Hydrogen	1
Proto-calcium	10
Proto-magnesium	12
Oxygen	16

So much, then, for a possible reconciliation. The next point to be considered is, is depolymerisation on such a small scale sufficient?

To do this we have to see the basis of the atomic weight of oxygen 16, and consider the series question in relation to oxygen. This necessitates a digression.

The simplest case presented in series phenomena is that placed before us by sodium and other elements which run through all their known spectral changes at a low temperature. Dealing with the line spectrum stage we have three "series," one principal and two subordinate (first and second). The former contains the orange line D, constantly seen at all temperatures, the first subordinate the red line, the second subordinate the green line, representatives of two series of lines which are best seen both in the flame and arc.

The two subordinate series of sodium, like those of all other elements so far examined, have the peculiarity that they end at nearly the same wave-length, while the end of the principal series occurs at a different, sometimes widely different, wave-length. This is a touchstone of the highest importance, as we shall see; it points to a solidarity of the two subordinate series, and to a difference between them and the principal series.

Although the original idea was that all three series were produced by the vibrations of the same molecule, observations of the sodium phenomena alone are simply and sufficiently explained by supposing that we have three different masses vibrating, and that two of them, producing the subordinate series, can be broken up by heat, while that producing the principal series cannot. The series represented by the red and green lines seen best at the lower temperatures have been seen alone, and it is a matter of common experience that the orange line representing the principal series is generally seen alone: it is not abolished at high temperature as the others are. Because the mass vibrations of which give us the orange line is produced by the breaking up of more complex forms at a low stage of heat, and it cannot be destroyed by the means at our command, it is the common representative of the element sodium. Because the masses the vibrations of which produce the two subordinate series represented by the red and green lines are easily destroyed by heat, they are more rarely seen, scarcely ever at high temperatures when the quantity is small, since, as I pointed out years ago, "the more there is to dissociate, the more time is required to run through the series, and the better the first stages are seen."

This view is greatly strengthened by considering another substance which, if we accept Pickering's and Rydberg's results, has, like sodium, three series, one principal and two subordinates in quite orthodox fashion. I refer to hydrogen.

Till a short time ago we only knew of one "series" of hydrogen, and on this ground Rydberg assumed it to represent the finest form of matter known, regarding the other substances which give three normal series as more complex. This idea is in harmony with the view expressed above.

Pickering in 1897 announced the discovery in the stars of another series, and seeing that this ends in the same part of the spectrum as the other, we can provisionally regard the terrestrial and stellar hydrogen as representing the first and second subordinate series.

Rydberg in the same year gave reasons for supposing that one line seen chiefly in the bright-line stars may represent still another series of hydrogen which we may take as the principal series. The other lines in this series he calculated to be out of range.

If we accept all these conclusions we must regard hydrogen as identical with sodium in its series conditions. But there is this tremendous difference. In sodium we

easily at low temperatures—the bunsen is sufficient—see all three series, while in the case of hydrogen even the Spottiswoode coil can show us nothing more than one of the subordinate series. At the same time, the other subordinate and the principal series are visible in stars which we have many reasons for believing to be hotter than the spark produced by the Spottiswoode coil.

The argument for the existence of three different masses producing the three different series derived from the sodium observations is therefore greatly strengthened by what we now know of hydrogen.

I shall therefore assume it in what follows, and now return from the digression.

Oxygen, instead of having three series like metals of low melting point such as sodium, and the gas hydrogen, has six. These six have been divided by Runge and Paschen into two normal sets of three, each set possessing one principal and two subordinate series.

There is evidently a new problem before us; we require to add the series of hydrogen to the series of sodium to get a "series" result similar to that obtained from oxygen.

Before we go further it will be well to consider the possible order of simplifications. Let us take the simplest case represented by sodium and hydrogen in the first instance. The facts are shown in the following table:—

		<i>High temperature.</i>						
		<i>Sodium.</i>		<i>Hydrogen.</i>				
Line stage	{	Principal	{	Celestial and terrestrial vapour.	Line stage	{	Principal	} Celestial gas.
		Subordinate		Terrestrial vapour.			Subordinate	
		Flutings		Solid and liquid.			Structure spectrum	
Continuous	Continuous

Low temperature.

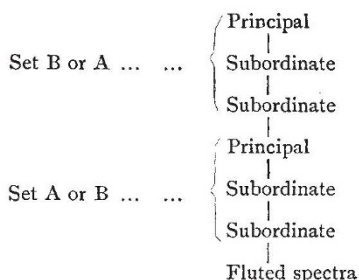
We may now bring these results to bear upon oxygen. We learned first from Egeroff that this gas at ordinary temperature and pressure is so molecularly constituted that it produces a fluted absorption in the red part of the spectrum. On account of the constancy of the results obtained by chemists we cannot be dealing with a mixture of molecules, the fluting absorption therefore must be produced by molecules of one complexity having an "atomic weight" of 16.

If we subject it to an induced current at low pressure (at which the action of such a current is feeblest), it at once breaks up into two normal sets of three series, that is six series altogether; it is almost impossible to consider this state of things in the light of what happens in the case of sodium and hydrogen without assuming on the ordinary chemical view that the "molecule" with the fluted spectrum is broken up into two, until finally we get—

		<i>High Temperature.</i>	
		SET A.	SET B.
Line spectrum	{	Principal series	Principal series.
		Subordinate	Subordinate.
		Subordinate	Subordinate.
} Fluted spectrum.			
<i>Low temperature.</i>			

But if we accept this, we give up depolymerisation, for the molecules of the subordinate series of sets A and B thus produced cannot be identical because their spectra are not identical.

If we hold to depolymerisation we must arrange matters thus—



and we get six depolymerisations.

The number of lines measured by Runge and Paschen in the spectrum of oxygen at low temperature was 76; of these the six series referred to contain 56, leaving 20 residual lines. Now if we employ a strong induced current at atmospheric pressure, we practically extinguish these six series of lines and produce a new spectrum altogether, containing a still greater number of lines: 114, according to Neovius. Only one line is common to his table and that of Runge and Paschen. About the series conditioning of these new lines we are at present profoundly ignorant.

Let us take the simplest course in harmony with the principle of continuity, and suppose that the great number of new lines is due to the breaking up of the molecules of the upper principal series given in the previous table into representatives of a still finer form, as hydrogen, as we know it, is broken up into a finer form at the highest stellar temperatures.

Have we, on the line of reasoning we are pursuing, any means of estimating the number of finer forms which may be at work to produce the 113 new lines?

One possible way—a statistical way—seems open to us. Taking the number of lines already recorded in the spectra roughly between λ 7000 and λ 2600 of the following substances, which give us three series—lithium, sodium, potassium, helium, asterium, hydrogen—we find that the number of lines in each series and the total numbers are as follows:—

	Maximum number.	Minimum number.	Average number.
Principal series ...	10 Ast	1 H	7
First subordinate ...	17 He	6 Na	9
Second subordinate...	12-He	4 Li	8
Totals	39	11	24

This indicates that in oxygen we are slightly above the average with $\frac{56}{2} = 28$ lines per set. If we take the

facts for oxygen itself, which give us 56 lines for two sets of three, the 113 lines will give almost exactly four additional sets of three series, and therefore the possibility of twelve more depolymerisations if this method of simplification is considered.

Of course we can halve the number of depolymerisations by assuming that the fluting molecule instead of being depolymerised is broken up into x and y , the bases of the two systems of series.

Now it is this last crop of new lines alone which are represented in the hottest stars, and no one, I think, will now urge that some kind of simplification which may include depolymerisation has not taken place before they were brought into evidence.

Our base of 16 then vanishes, and with it the previously considered possible atomic weights of the forms of magnesium and calcium which precede the appearance of oxygen in the hottest stars. We must therefore assume further depolymerisations in the case of these metals beyond those considered in the first instance.

I now come to another point. How do the above considerations bear upon hydrogen with its atomic weight of 1? Of this hydrogen we know nothing spectroscopically. There is evidence that it is broken up into something which gives the complicated structure spectrum with hundreds of lines not yet sorted into series, again into the one series seen in our laboratories and in the cooler stars, still again into two other forms we cannot get here.

Let us apply the statistical method we employed in the case of oxygen.

In the region included in these inquiries the number of hydrogen lines in the three series referred to is 17. Hasselberg has measured 454 lines in the structure spectrum between λ 642 and 441. Now if this spectrum is built up of series similar to those observed at the highest temperatures, we must have more (seeing that Hasselberg's work was limited) than $\frac{454}{17} = \pm 27$ series or 9 sets of 3 each. We deal then altogether with 12 depolymerisations.

But to be on the safe side, let us assume 6 on the ground that the lines in the series may be more numerous, and that some of Hasselberg's lines may be due to flutings. It will be clear that the masses or "atomic weights" we arrive at must be very small. Here is the story:—

Spectrum.	Where existent.	Series, &c.	Mass.
Line spectrum ...	{	Celestial { Principal ...	'0019
		Subordinate ...	'0039
		Terrestrial { Subordinate ...	'0078
Fluted spectrum	{	Set B { Principal ...	'0156
		Subordinate ...	'0312
		Terrestrial { Subordinate ...	'0625
		Set A { Principal ...	'125
		Subordinate ...	'25
		Terrestrial { Subordinate ...	'5
Continuous spectrum...	{	Hydrogen weighed in the cold ...	1

Such a conclusion as this, and therefore the reasoning which has led up to it, must stand or fall according as science knows anything of such masses.

I shall show subsequently that, thanks to the investigations of Prof. J. J. Thomson, science is beginning to know a great deal of such masses, and the result of this work may therefore favour the view that polymerisation is a *vera causa* for molecular complexity, at all events in the cases of elements of low atomic weight.

Let us then consider the case of those elements the atomic weight of which is greater. In the first stages of evolution, in which we deal with substances of relatively low atomic weight, the stellar evidence supplies us with definite landmarks, and these are definite because the spectra of the hottest stars are not overcrowded with lines. After we have passed the gaseous and proto-metallic stages, however, we find the spectra full of lines which we see at the temperature of the arc, and metals of relatively high atomic weight and melting point are involved; the exact sequences are naturally more difficult to follow, and therefore the *method* of evolution may escape us.

Kayser and Runge have shown that the melting point has a profound influence on the "series" conditions. Those with the highest melting-points, such as barium and gold, present us with no series. There is generally such a flood of lines that it has been so far impossible to disentangle them; we have the "structure spectrum" of hydrogen repeated in these metals at arc temperatures in the so-called "arc spectrum."

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(To be continued.)