ON SPECTRUM SERIES.[1]

WE have now, I trust, obtained a general idea of inorganic evolution so far as stratigraphic geology is concerned. You may remember that I pointed out that the evidence for organic evolution not only depended upon the various vegetable and animal forms which had been found in the various strata of the earth's crust from the pre-Laurentian up to the Recent times, but that the science of embryology had also been brought into play, and that a succession of forms in the individual was there to attest the general line of descent. To-night we have to deal with the spectroscope and the motions of the smallest units of inorganic matter which we can get at, and to compare the results obtained in this way with some of those that the biologist has arrived at by means of the microscopic examination of the smallest unit forms that he can observe. From the spectrum point of view, this inquiry is included in the word "series." In the study of series of lines in different spectra, we are on the same ground plan as the biologist is when he is studying what he calls cytology, or the laws of cells.

To explain what is meant by "series" I will refer to one or two photographs of what are termed fluted spectra. You will observe that such a spectrum is perfectly rhythmic from end to end. The whole of a fluting may be regarded as a unit; it is generally strongest towards the right or the red end of the spectrum, its elements gradually becoming dimmer as we approach the violet end. But a fluting is generally more than this; it is built up of subsidiary flutings. Each of the subdivisions of it is in itself an almost exact representation in the small of what the whole thing is in the great; so that we have the conceptions of a simple fluting and a compound fluting. The compound flutings are well represented in the flu tings of carbon. It is by means of such photographs that the existence of carbon in the sun has been determined. Each of the finer lines in one of the first elements of the compound fluting has a dark line corresponding with it among the Fraunhofer lines. In the case of the spectrum of nitrogen we get the same exquisite rhythm, the same intensification of the series of lines towards the red, and the same division of some of the larger flutings into smaller divisions; so that, as I said before, we have to consider flutings really as compound and not as simple phenomena. When we leave these flutings and study an ordinary line spectrum, in a great many cases all rhythm seems to have disappeared. There is apparently no law and no order. Let us take the lines seen when we expose the gases obtained from the mineral cleveite to the action of an electric current.[1] We observe that all rhythm has gone, and there seems to be a very irregular distribution; but when we come to sort those lines out into series, we find that there is just the same exquisite order that we get in the case of the flutings. You notice in the photograph all the lines higgledy-piggledy, the next photograph will show that they have all been resolved into two sets of three series which very much resemble those that we saw before; that is to say, they gradually get nearer together towards the violet, and they all get stronger towards the red. We have then two constituents of the cleveite gases, asterium and helium, and we find that their irregular line spectra when analysed into these series are translated into a wonderful order. I suggested many years ago that the lines in the ordinary line spectrum of a substance may really be remnants of compound flutings, and such inquiries as those that I have to refer to to-night really seem to justify that suggestion. Very well, then, we arrive at the fact that the term "series" is one employed to related lines. It is impossible to suppose that these wonderful rhythmic series of lines are not related in some way to each other, and that being so we have to study their wave-lengths, that is, their positions in the case of any one element; and not only so, but to see if any relation exists between the lines of different elements.

FIG. 1.—Compound flutings of carbon.

The history of this quite modern inquiry is not very long, but short as it is I only propose to refer to it in the briefest possible manner.

The first attempt to discover regularities in the lines of spectra was made by Lecoq de Boisbaudran,[2] who investigated the spectrum of nitrogen. The conclusions he arrived at suggested that the luminiferous vibrations of the molecules could be compared with the laws of sound, but as these were not based on wave-length determinations of sufficient accuracy, and also were not confirmed by Thalén, no great weight could be attached to the result.

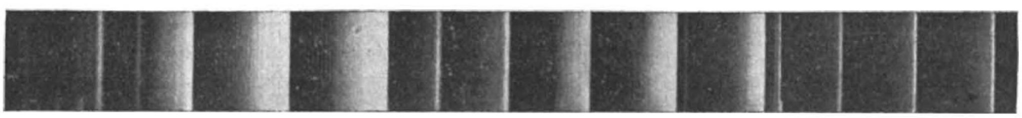

FIG. 2.—Simple flutings of nitrogen.

Stoney,[3] who followed up these investigations, was more successful; he showed that the hydrogen lines C, F, and *h* were connected by the relationship 20 : 27 : 32.

Several other workers—Reynolds, Soret, &c.—took the subject up, but it was left for the more thorough work of Schuster[4] to show that this theory could no

[1] A Lecture to Working Men delivered at the Museum of Practical Geology, on May 1, by Prof. Sir Norman Lockyer, K.C.B., F.R.S.

[1] It has always been customary with me in reproducing spectra in the form of illustrations to show the red end of the spectrum on the right hand side and the violet end on the left. As most of the workers on "series" have adopted the opposite way, I propose *in this lecture* to depart from my usual custom and place the red in series spectra on the left, so that all the series illustrations may be comparable *inter se*.

[2] *Comptes rendus* (1869), 69, 694.

[3] *Phil. Mag.*, 1871 [4], 41, 291.

[4] Brit. Assoc. Report, 1880; *Proc. R.S.* (1881), 31, 337.

longer be considered as expressing the law connecting the mutual relationships between the wave-lengths of lines in a spectrum.

Liveing and Dewar[1] next called attention to the fact that the distance between two consecutive lines of these groupings decreases with diminishing wave-lengths, so that eventually the lines asymptotically approach a limit. "Harmonic" was the term they used to express such a series of similar groups of lines.

It was, however, the work of Balmer which gave the subject the impetus by which it has of late years made great progress.

Balmer[2] published a formula by which the positions of the hydrogen lines could be calculated with wonderful accuracy. The formula is as follows :—

$$\lambda = A \frac{n^2}{n^2 - 4},$$

in which λ is the wave-length in vacuo of the line to be calculated, A a constant common for all the lines, and n one of a series of numbers from 3 to 15.

The constant A, according to Cornu's measurements, is 3645·42 Ångstrom units, or, using Ames' more correct value, 3647·20 Ångstrom units.

Simultaneously with Balmer's discovery, Cornu[3] pointed out that the lines of aluminium and thallium, which are readily reversible, bear a definite relation to those of hydrogen, while at a later date Deslandres[4] published a formula from which could be calculated the wave-lengths of the lines composing the bands of numerous elements.

The above brief history brings us down to the year 1887, in which Kayser and Runge[5] began their series of minute investigations dealing with a great number of elements. It was also about this time that Rydberg[6] commenced to take up the subject.

I will state generally the ground over which their work has extended. They have attacked the question mathematically from different standpoints. In the following table I give the formula employed by Kayser and Runge, and that employed by Rydberg.

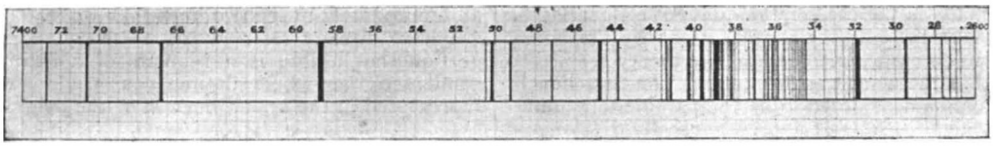

FIG. 3.—Spectrum of the Cleveite gases.

Formulae for Calculating Series.

Kayser and Runge	Rydberg.
$\frac{1}{\lambda} = A + Bn^{-2} + Cn^{-4}$ where λ = wave-length (or $\frac{1}{\lambda}$ = wave frequency) $n = 3, 4, 5, \ldots$ A, B, C = constants calculated for each series. The constants for the principal series are different from those used in the subordinate series. For sub-series of Na, K, Rb, Cs, Cu, Ag, Al, In, and Tl, the constants B and C are identical. For all series the constant B does not vary by more than 22 per cent. This constant B corresponds to Rydberg's N_0.	$n = n_0 - \frac{N_0}{(m+\mu)^2}$ where n = wave frequency $m = 1, 2, 3, \ldots$ N_0 = 109721·6 (a constant applicable to all series of every element) n_0, μ = characteristic constants varying with each series. In the above formula, when $m = \infty$, $n = n_0$; or n_0 is the limit which the number of waves n approaches when m is infinite. The value of N_0 is assumed by Rydberg to be constant, as it varies only slightly, and this variation may be due to uncertain data.

You will see that they are not by any means identical, but both deal with wave frequency, that is to say, the number of waves in a given unit of length. Then they employ a certain sign, n, to represent the successive integers which have to be used to define certain of their terms, and in addition to this we get certain constants which are calculated for each series. The most interesting consideration from this point of view is that Rydberg found that there was one constant which he could use in order to search for the series of lines in the spectra of all the chemical elements with which he worked. There was no common constant similar

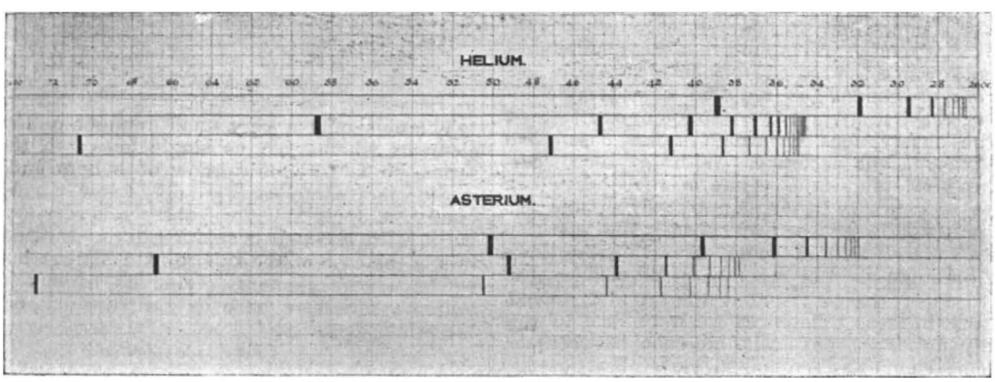

FIG. 4.—Spectrum of the Cleveite gases sorted out into six regular series.

1 *Phil. Trans.*, 1883, p. 213, and previously.
2 *Wied. Ann.* (1885), 25, 80.
3 *Comptes rendus* (1885), 100, 1181.
4 *Ibid.* (1886), 103, 375 ; (1887), 104, 972.
5 "Ueber die Spectren der Elemente" (*Abhandlungen d. K. Akad. Berlin*, 1880, 1889, 1890, 1891, 1892, 1893.
6 *Svenska Vetenskap. Akad. Handlingar*, Stockholm (1890), 23, No. 11 ; *Wied. Annalen* (1893), 50, 629 ; (1894), 52, 119.

to this used by Kayser and Runge, but they found that some of their constants varied little from element to element. In that way they not only obtained the first term of a series, but the whole series throughout the entire length of the spectrum, and where observations had been made in the case of the different elements they could of course check their calculations by the actual observations so made, and see how the theory seemed to be justified as the work was extended. The first line in a series must be considered to be comparable to a fundamental note in music. It represents really the longest light wave in the same way that the fundamental note in music represents the longest sound wave. Both series of results, obtained in the way I have described by Kayser and Runge and by Rydberg, show us that, in many cases, we may be almost certain to obtain from the higgledy-piggledy arrangement of the lines in the spectrum of any one substance two or three beautiful regular series like those that I have already shown you in the case of helium and asterium. There is a little difference in the nomenclature employed by the investigators to whom I have referred, as shown in the annexed table.

Series Nomenclature.

Intensity.	Kayser and Runge.	Rydberg.
Strongest	Principal series	Principal series
Weaker	1st subordinate series	Nebulous series
Weakest	2nd subordinate series	Sharp series

The strongest lines which they observed at the temperatures they worked with, they put into what they call a "principal series," and then the weaker lines were distributed among other two series. Kayser and Runge called them the "first-" and "second-subordinate" series; Rydberg calls them the "nebulous-series" and the "sharp-series." It is important to remember this in case you come across any reference to these matters, in order that you may see what the exact equivalent is. The lines of the principal series almost always reverse themselves very easily indeed—that is to say, that the absorption is indicated by them more readily than it is by the other lines. Then, when we come to the second subordinate or sharp series, it is found that these sometimes broaden out towards the red end of the spectrum.

This work, of course, has required considerable investigation; the first attempts were not quite satisfactory, because the observations on which it was based had not been of sufficient accuracy. With greater dispersion it has been found that some of the lines which were supposed at first to be single are really double; so that it is quite usual now when we consider this question of series to suppose that in some cases the series are composed of single lines, in other cases of doubles, and in other cases of triplets; and it was at first, indeed, imagined that in these differences we were face to face with a very important physical difference between the various elements, but Rydberg has suggested that possibly after all it may be a difference merely in the seeing.

He says:[1]

"The difference between the doubles and triplets is only relative. This opinion is confirmed by the fact that the triplets appear often in the form of doubles, the most refrangible component not having sufficient intensity to become visible. Further, the relative intensity of the components of the doubles seems equal to that of the two less refrangible components of the triplets.

"For these reasons I have dared to propose the hypothesis that the two kinds of component rays are of the same order, or that the doubles are only triplets of which the most refrangible component is too feeble to be seen, or has perhaps the absolute value of zero. . . ."

If the lines are more difficult to see, and if the sub-series of lines get stronger towards either the red end or the blue end, then we are more likely to see one line than two, and more likely to see two lines than three.

I have already referred to the many years old suggestion that a line is a remnant of a fluting. If you could see the whole fluting, you would see what is represented in the upper horizon of the diagram; if you

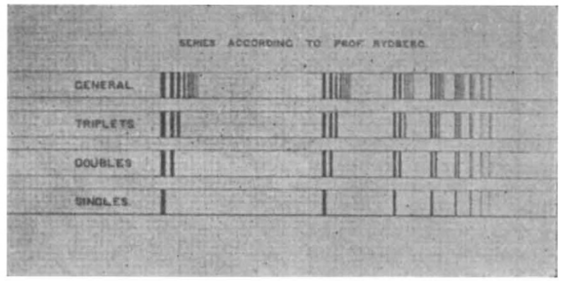

FIG. 5.—Diagram illustrating Rydberg's idea of the appearance of triplets, doubles, &c.

could not see the whole of it, you would get what is represented in the second horizon, that is to say, a triplet. If the third line were very difficult of observation you would only see a doublet, and if the inside line were weaker than the other you would only see a single line.

Single lines		Doubles		Triplets	
Principal series	Subordinate series	Principal series	Subordinate series	Principal series	Subordinate series
Helium			Helium	Oxygen	Oxygen
Asterium	Asterium	Hydrogen (?)	Hydrogen	Sulphur	Sulphur
		Lithium (?)	Lithium (?)	Selenium	Selenium
		Sodium	Sodium		Magnesium
		Potassium	Potassium		Calcium
		Rubidium			Strontium
		Cobalt			Zinc
			Copper		Cadmium
			Silver		Mercury
			Aluminium		
			Indium		
			Thallium		

There is only a very small number of the chemical elements which give us single lines; in the principal series, so far, we only know of helium and asterium: in the subordinate series we only know of asterium. The number of doubles, you will observe, is very much greater, but it is not so great in relation to the principal series as it is in the case of the subordinate series; but although we have nine elements giving us triplets in the subordinate series, we have only three which give them in the principal series.

(To be continued.)

THE DOVER MEETING OF THE BRITISH ASSOCIATION.

THE final arrangements for this year's meeting are now sufficiently completed for a fairly accurate forecast to be made. Whether the meeting will be large or small it is still too early to judge, but whether large or small it will certainly be a very interesting one. As to accommodation in the town, there is little doubt but that at the time of meeting ample accommodation will be available, though the committee have had great difficulties in inducing hotel keepers and lodging-house owners to

[1] *Kon. Sv. Vet. Ak. Hand.*, vol. 23, ii. p. 135.