

CLASSICS OF SCIENCE:

Moseley's Atomic Numbers

Physics—Chemistry

In these classic researches Moseley solved the riddle of the true order of the elements, and explained the irregularities of Mendeleeff's periodic table.

The London, Edinburgh and Dublin PHILOSOPHICAL MAGAZINE and Journal of Science. Sixth Series.

The first extract is from Vol. XXVI, No. CLI, July, 1913; the second from Vol. XXVI, No. CLVI, December, 1913; the third from Vol. XXVII, No. CLX, April, 1914.

The Reflexion of the X-rays. By H. G. J. Moseley, M. A., John Harling Fellow, and C. G. Darwin, M. A., Lecturer in Mathematical Physics in the University of Manchester.

The discovery in July, 1912, by Friedrich and Knipping that the X-rays can show interference has opened up a new region to research. It had been suggested to them by Laue that the ordered arrangement of the atoms in a crystal would do the same for X-rays that a diffraction-grating does for light. They therefore sent a fine beam of X-rays through a thin crystal of zinc-blende on to a photographic plate. After prolonged exposure to the radiation the plate showed an elaborate system of spots surrounding the central image. These spots were caused by fine beams of X-rays, which came from the crystal. Explanations of this phenomenon have been offered by Laue and by W. L. Bragg. The following is a brief statement of W. L. Bragg's theory.

It is known that every atom in a crystal scatters a small fraction of the incident radiation. Since the atoms are regularly arranged these scattered disturbances have definite time relations. In certain directions a number of scattered disturbances reinforce one another, and so give rise to a new disturbance of considerable strength. The co-operating disturbances come from atoms which lie in a plane. This plane, the incident beam, and the direction of the new beam have the same geometrical relation as have a mirror, an incident ray, and the reflected ray. Wherever a plane containing many atoms can be drawn in the crystal a ray will be found in the direction which is the reflexion in this plane of the incident beam. The position of every spot in Friedrich and Knipping's photographs can be found from this principle. A cleavage-plane is exceptionally rich in atoms,



H. G. J. MOSELEY in his laboratory

and Bragg confirmed his theory by throwing a beam of X-rays on to a cleavage surface of mica, and observing a strong image in the position which an optically reflected beam would occupy.

The High-Frequency Spectra of the Elements. By H. G. J. Moseley, M. A.

. . . Twelve elements have so far been examined. The ten given in Table I were chosen as forming a continuous series with only one gap. It was hoped in this way to bring out clearly any systematic results. The inclusion of nickel was of special interest owing to its anomalous position in the periodic system. Radiations from these substances are readily excited, and the large angles of reflexion make it easy to measure the wave-lengths with accuracy. Calcium alone gave any trouble. In this case, owing to the high absorption coefficient of the principal radiation—about 1200^{-1} cm. in aluminum—the X-ray tube was provided with a window of goldbeaters' skin and the air between the crystal and the photographic plate displaced by hydrogen. The layer of lime which covered the surface of the metal gave off such a quantity of gas that the

X-rays could only be excited for a second or two at a time. Brass was substituted for zinc to avoid volatilization by the intense heat generated at the point struck by the cathode rays. Ferrovandium (35 per cent. V) and ferro-titanium (23 per cent. Ti), for which I am indebted to the International Vanadium Co., proved convenient substitutes for the pure elements, which are not easily obtained in the solid form.

Plate XXIII shows the spectra in the third order placed approximately in register. Those parts of the photographs which represent the same angle of reflexion are in the same vertical line. The actual angles can be taken from Table I. It is to be seen that the spectrum of each element consists of two lines. Of these the stronger has been called alpha in the table, and the weaker beta. The lines found on any of the plates besides alpha and beta were almost certainly all due to impurities. Thus in both the third and second order the cobalt spectrum shows Ni alpha very strongly and Fe alpha faintly. In the third order the nickel spectrum shows Mn alpha₂ faintly. The brass spectra naturally show alpha and beta both of Cu and Zn, but Zn beta₂ has not yet been found. In the second order the ferro-vandium and ferro-titanium spectra show very intense third-order Fe lines, and the former also shows Cu alpha₃ faintly. The Co contained Ni and 0.8 per cent. Fe, the Ni 2.2 per cent. Mn, and the V only a trace of Cu. No other lines have been found; but a search over a wide range of wave-lengths has been made only for one or two elements, and perhaps prolonged exposures, which have not yet been attempted, will show more complex spectra. The prevalence of lines due to impurities suggests that this may prove a powerful method of chemical analysis. Its advantage over ordinary spectroscopic methods lies in the simplicity of the spectra and the impossibility of one substance masking the radiation from another. It may even lead to the discovery of missing elements, as it will be possible to predict the position of their characteristic lines.

It will be seen from Table I that the wave-lengths calculated from the two orders are in good agreement. The third order gives the stronger reflexion, and as (*Turn to next page*)

Atomic Numbers—Continued

the angles dealt with are the larger these results are the more accurate. The similarity of the different spectra is shown by the fact that the two lines alpha and beta remain approximately constant, not only in relative intensity but also in relative wavelength. The frequency of beta increases, however, slightly faster than that of alpha. . . .

We have here a proof that there is in the atom a fundamental quantity, which increases by regular steps as we pass from one element to the next. This quantity can only be the charge on the central positive nucleus, of the existence of which we already have definite proof. Rutherford has shown, from the magnitude of the scattering of alpha particles by matter, that this nucleus carries a + charge approxi-

mately equal to that of $\frac{A}{2}$ electrons,

where A is the atomic weight. Barkla, from the scattering of X-rays by matter, has shown that the number of electrons in an atom is roughly $\frac{A}{2}$,

which for an electrically neutral atom comes to the same thing. Now atomic weights increase on the average by about 2 units at a time, and this strongly suggests the view that N increases from atom to atom always by a single electronic unit. We are therefore led by experiment to the view that N is the same as the number of the place occupied by the element in the periodic system. This atomic number is then for H 1, for He 2, for Li 3 . . . for Ca 20 . . . for Zn 30, etc. This theory was originated by Broek and since used by Bohr. We can confidently predict that in the few cases in which the order of the atomic weights A clashes with the chemical order of the periodic system, the chemical properties are governed by N; while A is itself probably a complicated function of N. The very close similarity between the X-ray spectra of the different elements shows that these radiations originate inside the atom, and have no direct connection with the complicated light-spectra and chemical properties which are governed by the structure of its surface.

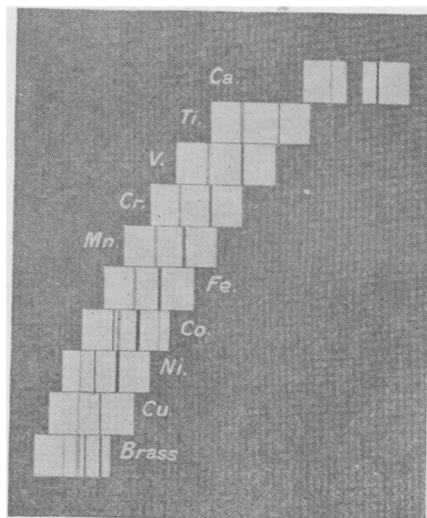
The High-Frequency Spectra of the Elements. Part II. By H. G. J. Moseley, M. A.

The first part of this paper dealt with a method of photographing X-ray spectra, and included the spectra of a dozen elements. More than

thirty other elements have now been investigated, and simple laws have been found which govern the results, and make it possible to predict with confidence the position of the principal lines in the spectrum of any element from aluminium to gold. The present contribution is a general preliminary survey, which claims neither to be complete nor very accurate. . . .

The results obtained for the spectra of the L series are given in Table II. and plotted in fig. 3. These spectra contain five lines, alpha, beta, gamma delta, eta, reckoned in order of decreasing wave-length and decreasing intensity. There is also always a faint companion alpha prime on the long wave-length side of alpha, a rather faint line phi between beta and gamma for the rare earth elements at least, and a number of very faint lines of wave-length greater than alpha. Of these, alpha, beta, phi and gamma have been systematically measured with the object of finding out how the spectrum alters from one element to another. The fact that often values are not given for all these lines merely indicates the incompleteness of the work. The spectra, so far as they have been examined, are so entirely similar that without doubt alpha, beta and gamma at least always exist. Often gamma was not included in the limited ranges of wave-lengths which can be photographed on one plate. Sometimes lines have not been measured, either on account of faintness or of the confusing proximity of lines due to impurities.

Lines due to impurities were frequently present, but caused little trouble except in the rare earth group.



X-RAY SPECTRA OF TEN ELEMENTS (Plate XXIII)

Conclusions

In Fig. 3 the spectra of the elements are arranged on horizontal lines spaced at equal distances. The order chosen for the elements is the order of the atomic weights, except in the cases of A, Co, and Te, where this clashes with the order of the chemical properties. Vacant lines have been left for an element between Mo and Ru, an element between Nd and Sa, and an element between W and Os, none of which are yet known, while Tm, which Welsbach has separated into two constituents, is given two lines. This is equivalent to assigning to successive elements a series of successive characteristic integers. On this principle the integer N for Al, the thirteenth element, has been taken to be 13, and the values of N then assumed by the other elements are given on the left-hand side of fig. 3. This proceeding is justified by the fact that it introduces perfect regularity into the X-ray spectra. . . .

Now if either the elements were not characterized by these integers, or any mistake had been made in the order chosen or in the number of places left for unknown elements, these regularities would at once disappear. We can therefore conclude from the evidence of the X-ray spectra alone, without using any theory of atomic structure, that these integers are really characteristic of the elements.

Now Rutherford has proved that the most important constituent of an atom is its central positively charged nucleus, and Van den Broek has put forward the view that the charge carried by this nucleus is in all cases an integral multiple of the charge on the hydrogen nucleus. There is every reason to suppose that the integer which controls the X-ray spectrum is the same as the number of electrical units in the nucleus, and these experiments therefore give the strongest possible support to the hypothesis of van den Broek. Soddy has pointed out that the chemical properties of the radio-elements are strong evidence that this hypothesis is true for the elements from thallium to uranium, so that its general validity would now seem to be established.

Henry Gwyn-Jeffreys Moseley (1887-1915) had barely completed the researches reprinted here when the World War and England's disastrous volunteer system of raising armies dragged him from the laboratory to death at Gallipoli.

Science News-Letter, March 30, 1929