## Letters to the Editor.

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### X-Rays—Internal Absorption and 'Spark' Lines.

IN recent work by Mr. A. M. Cassie and myself (now being prepared for publication), it has been possible to study some of the details of the process of 'internal' absorption of an X-ray by the atom in which it is excited. This type of absorption has played an important part in the elucidation of $\beta$- and $\gamma$-ray spectra, and has been fully discussed, notably by Ellis and Skinner in Great Britain, and by Meitner, de Broglie, Thibaud, and others. An excellent summary of the work on the X-ray side is to be found in Bothe's article in vol. 23 of the new Geiger and Scheel "Handbuch."

In the X-ray domain the effects of internal absorption have been beautifully demonstrated by P. Auger in his Wilson tracks produced by X-rays in heavy gases. Auger's results show that in the $K$ excitation of argon, about 90 per cent. of the fluorescent $K$ quanta are absorbed by the atoms in which they are excited, with emission of tertiary photoelectrons: this "specially privileged" absorption becomes less marked with heavier elements (about 50 per cent. for krypton, and, according to Meitner, about 10 per cent. for elements of atomic number round 85), but is in any case amazingly high.

In our experiments, the secondary cathode rays emerging from a 'target' irradiated by X-rays are drawn out into a magnetic spectrum, and their energies are measured as in earlier work by de Broglie, Whiddington, Robinson, and others. In the present work a great deal of 'white' radiation is allowed to remain in the X-ray beam, and in consequence the fluorescent X-ray spectrum of the target is strongly excited. The corpuscular spectra show many lines which are due to the internal conversion of the fluorescent X-rays, or, alternatively, to radiationless (Rosseland) readjustments within the atom which lead to the expulsion of 'photoelectrons of the second kind.' For brevity these lines may be called 'fluorescent' lines, to distinguish them from the 'normal' lines arising from the external absorption of the constituents of the primary X-ray beam.

There are very many of these fluorescent lines, some of them very faint and difficult to resolve, and the measurements are not yet complete. It is certain, however, that most of these electrons emerge with considerably less energy than would be expected if they came from a normal atom: the deficiency is of the order 50-100 electron-volts—far too big for experimental error. There can be little doubt that they come from atoms which were already ionised, and, therefore, had abnormally high energy levels. This energy defect would be inappreciable in a fast $\beta$-ray, and scarcely detectable from the Wilson tracks.

The processes taking place are easily visualised; for example, as a possible sequence we may have in successive stages following the ejection of a $K$ electron from the target—(1) an $L_{\text{III}}$ electron falling into the vacant place with emission of a $K\alpha_1$ quantum of fluorescent X-radiation; (2) internal absorption of this quantum, with expulsion of a photoelectron from an $L, M$ . . . shell, either while the vacant place in $L_{\text{III}}$ is still untenanted, or after $L_{\text{III}}$ has been completed (say by an $M$ electron), but while the atom is still ionised in an outer shell. This is typical of many possible processes of the same kind (cf. Auger, *J. Phys. et le Radium*, June 1925), all leading to atoms which are multiply ionised in their X-ray shells. So far as the final result is concerned, it is immaterial whether this takes place as above, or by way of radiationless changes.

The multiply ionised atoms produced in this way ought to be competent to account for at least some of the abnormal lines observed in nearly all X-ray spectrograms (Coster's 'non-diagram' or Wentzel's 'spark' lines) as faint satellites on the high frequency sides of the series X-ray lines. Wentzel has worked out in detail the theory of these 'spark' lines, on the assumption that they are due to multiply ionised atoms. While there can be no doubt of the essential accuracy of Wentzel's work, the experimental evidence as to the manner in which the multiple ionisation is brought about is still very unsatisfactory (cf. Bäcklin, *Zeit. für Physik*, **27**, p. 30). Dr. Wentzel suggested to me some time ago that my corpuscular spectra might show traces of multiple ionisation produced by a single X-ray quantum, but so far I have got no evidence of this (in any case these lines would be very faint). Internal absorption obviously could not account for the production of spark lines in the $K$ series; that is, it could not be expected to produce atoms in the $K^2$, $KL$ . . . conditions required by Wentzel—but it certainly could account qualitatively for the existence of $L$ spark lines. As shown in the above example, once the $K$ excitation limit is reached, there will be large numbers of atoms in $L^2$, $LM$ . . . conditions: this provides a very satisfactory explanation of the effect observed by Siegbahn and Larsson (*Ark. Mat., Ast. och Fysik*, **18**, 1924). These experimenters, investigating the $L$ spectrum of molybdenum with a tube operated at different voltages, found no new spark lines between 4 and 20 kilovolts. At 20 kv. a new line first appeared, and no further line appeared even at 40 kv. 20 kv. is just more than is required to excite molybdenum $K$, and is certainly insufficient for simultaneous $K$, $L$ ionisation.

We have obtained direct and very striking evidence of the fundamental difference between internal and external absorption, by experiments in which a thin copper target was exposed under identical conditions to (1) copper $K\alpha_1$ primary rays and (2) white radiation from a molybdenum tube operated at high voltage. In case (1) we get the normal copper $L$ lines, $L_{\text{I}}$ and $(L_{\text{II}}, L_{\text{III}})$—the latter pair as an unseparated doublet—resulting from external absorption of the primary copper $K\alpha_1$. In case (2), following the ejection of a $K$ electron, we have internal absorption of the same quantum. The corresponding $L$ lines of the 'fluorescent' spectrum are definitely displaced 0·6 mm. (about 60 to 70 volts) on the plates in the direction of smaller energy, and there is no visible trace of the 'normal' lines. Further—and this is most significant—the intensity ratio is entirely changed: with external absorption of $K\alpha_1$, $L_{\text{I}}$ is slightly more intense than $(L_{\text{II}}, L_{\text{III}})$ (cf. Robinson, *Roy. Soc. Proc.*, 1923). In case (2) the doublet $(L_{\text{II}}, L_{\text{III}})$ is by far the more intense.

Similar effects have been noticed in $\beta$-ray spectra, but in our experiments the phenomenon is naturally under greater control, and the interpretation more direct.

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