54. COMPLEX X-RAY CHARACTERISTIC SPECTRA

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(*Nature*, **129**, 435, 1932)

It is well known that for the excitation of the characteristic X-ray spectra of elements, an electron has first to be removed from some internal level; when this is done, an electron from an outer level jumps to this vacant place, and characteristic radiation is emitted. The spectrum is called K, L, M. . . . .according to the level of the atom from which the electron was first removed.

This explanation suffices for the origin of the diagram lines, which show the same structure as lines due to alkalis, but there are, besides, other lines, the origin of which is still a matter of debate. Some of these have been traced to forbidden transitions;[1] but in addition, there are the so-called spark lines, which appear as faint satellites to the diagram lines. Hypotheses[2] have been advanced which ascribe these to double ionisation and single transition.

In this note we wish to direct attention to the existence of a third class of characteristic lines, which are due to *double ionisation and double transition.* Suppose in one single act of bombardment of the anticathode by electrons, two electrons are removed simultaneously from an internal level, say one from L_1, the other from L_2, and these places are filled up by simultaneous passage of electrons from higher levels, say one from M_1, the other from M_3. It can be shown from quantum principles and from analogy with optical spectra that one of the transitions will be allowed, the other forbidden, so that in the above example the transition may be written as $(L_1 L_2 \leftarrow M_1 M_3)$; it is a composite transition and is the sum of the two transitions (1) $L_2 \leftarrow M_3$, which is allowed, and (2) $L_1 \leftarrow M_1$, which is forbidden. Lines due to such transitions are quite common in optical spectra: for example, in the case of Ba $6s^2\ {}^1S_0 - 5d.\ 6p.\ {}^1P_1$ $\lambda 3501{\cdot}1$ cited by Russell and Saunders[3] in their classical paper on the spectra of alkaline earths.

There is no reason why double transitions should not occur in the X-ray region. But *their frequency will be approximately* double the frequency of the usual L-lines, and since the electron configuration in this case is $2s.\ 2p^5 \leftarrow 3s.\ 3d^9$, the lines will form a multiplet $({}^1P,\ {}^3P) \leftarrow ({}^1D,\ {}^3D)$, provided Russell-Saunders coupling continues to hold in such cases. *The fact that their frequency will be double the usual L-spectrum frequency marks them out as a distinct class.*

Attempts have been made in this laboratory to obtain such lines from a tungsten anticathode, and two lines have been obtained with the wave-lengths $\lambda = 723$ and 682 X.U. They are diffuse lines impressed on a continuous background, and may be found to be attended with satellites when higher resolution is used. These wave-lengths are approximately half the wave-length of tungsten L-lines. After searching the literature to determine whether such lines have been noticed by any previous worker, we find that Rogers[4] noted in 1923 the following lines from tungsten: $\lambda = 1450$, 1373, 1321, 1248·7, 1230, 1114, 1086 X.U. These have not been traced to the tungsten levels, or identified as satellites or nondiagram lines, and cannot be ascribed to any other element. But it will be seen that the wave-lengths of the first two of Rogers' lines are very nearly double the wave-length of the lines obtained by us. Hence it may be safely concluded that the lines obtained by Rogers are the same double transition lines obtained in the second order.

The full multiplet will be dispersed over a large wave-length range, and, with our present apparatus, such long exposures (amounting to a hundred hours) are needed that considerable time must elapse before the whole set of lines can be photographed. But the fact that double L-frequency lines have been obtained at all indicates that the ideas presented here are essentially sound.

We think that we have established the possibility of getting double transition lines constituting complex spectra in the X-ray region. To get double transition or multiple transition lines due to all elements will be a vast programme, but when this is done, it will probably afford us very useful material for working out coupling problems inside the atom. The idea probably explains the numerous critical levels obtained by Richardson and his students: for the most part, these levels have no apparent connexion[5] with the recognised X-ray levels which give rise to the diagram lines. This fact is at present inexplicable; but supposing the quantum theory can be adopted to explain the fact, then combining this with the ideas presented here, we find that we get an unforced explanation of the numerous levels obtained by Richardson, and need not give up the Bohr-Stoner levels (cf. Richardson[6]). The J-phenomenon also does not appear to be so inconceivable, as according to our views we may have characteristic lines approximately double the frequency of ordinary *K*-lines.*

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*The following cablegram dated Feb. 29 has been received from Prof. Saha:
Double transition *K*-line approximately double frequency *K*-alpha three obtained copper.—SAHA.

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55. ON THE β-RAY ACTIVITY OF RADIOACTIVE BODIES

(*Preliminary Communication*)

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(*Bull. Acad. Sci.*, (*Allahabad*) **5,** 257, 1934)

Received on November 6, 1933

INTRODUCTION

The β-ray activity of radioactive bodies has up till now proved to be a baffling problem. The points at issue are summarised in Gamow's *Constitution of Atomic Nuclei*, pp. 52-54, and in *Radiations from Radioactive Bodies* by Rutherford, Chadwick and Ellis. They are also discussed at some length by Bohr in his *Faraday Lecture* (Feb. 1932). We shall later quote freely from Bohr, but some fundamental difficulties may be pointed out at the outset.

The older view of the constitution of the nucleus was that it should be regarded as composed of A protons (A=mass number) and $A-Z$ electrons (Z=nuclear charge). A large number of these protons and electrons may exist in the compound form of α particles ($4p+2e$) or some other composite structures. But even allowing for these, the existence of a number of free electrons had to be postulated inside the nucleus. On the other hand, the evidence of hyperfine structure, as was first pointed out by de Kronig, definitely proves that the electron cannot exist in the free state in the nucleus, for then the magnetic moment of the nucleus should have the magnitude of the Bohr magneton, while the hyperfine structure of spectral lines definitely shows that the moment has the magnitude of the protonmagnet ($\frac{1}{1836}$ times the Bohr-magneton). At the present time, it is almost universally held that the nucleus consists of Z protons, and $A-Z$ neutrons, but it is quite possible that a number of these are combined in the form of α-particles, deutons, etc. *The nucleus contains no electrons free or bound.*[1,2]

But this conclusion is seemingly at variance with the observed fact that in a β-ray disintegrations the nuclei are observed to eject high speed electrons spontaneously. The situation is therefore paradoxical. Bohr puts it as follows :—

"Strictly speaking, we are not even justified in saying that a nucleus contains a definite number of electrons, but only that the negative electrification is equal to a whole number of units and in this sense, the expulsion of a β-ray from a nucleus may be regarded as the creation of an electron as a mechanical entity".

In a later passage, Bohr describes the other difficulties as follows :—

"As regards this last question, much theoretical interest has recently been aroused by the peculiar features exhibited by the β-ray expulsions. On the one hand, the parent elements have a definite rate of decay, expressed by a simple probability law, just as in the case of the α-ray disintegrations. On the other hand, the energy liberated in a single β-ray disintegration is found to vary within a wide continuous range, whereas the energy emitted in an α-ray disintegration, when due account is taken of the accompanying electromagnetic radiation and the mechanical energy conversion, appears to be the same for all atoms of the same element".

To the above remarks of Bohr, the following may be added :—

(*a*) The β-ray disintegration has been observed not only in the case of heavy elements, but also in the light elements potassium and rubidium (or rather the isotopes K^{41} and Rb^{87}). In the case of β-ray bodies associated with the main groups (U, Th, Ac), the life of β-ray bodies is found to vary from 16 years (RaD) to a few minutes, but the light elements K^{41} and Rb^{87} possess lives comparable