Letters to the Editor.

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Effective Wave-lengths of γ-Rays.

ONE of the difficulties in explaining the results of experiments on γ-rays is our lack of knowledge of the variation of intensity with wave-length in the spectrum of the γ-rays. This has led to the use of "effective" wave-lengths (two, in general, being needed because scattering and absorption coefficients vary with the wave-lengths in different manners), and values have been used, which, although incorrect, apparently help to explain the experimental results. For example, I have pointed out at two scientific meetings (American Physical Society, December 1922, and the British Association, Toronto, August 1924), that if we assume, as has been done by several physicists, that the effective wave-length of the γ-rays is about 0·02 Å.U., the secondary β-rays produced in light elements by the hard γ-rays of radium-C possess far too much energy to be recoil electrons (for the properties of which see a paper by Compton and Hubbard, *Physical Review*, 4, p. 439, 1924). Experimental evidence indicates that these β-rays are not photoelectrons. If they are recoil electrons, the effective wave-length of the γ-rays must be taken as about 0·008 Å.U. in order that we may account, on the quantum theory of scattering, for their observed energy. This result, which was first obtained by a comparison of the relative penetrating powers of the secondary β-rays and the β-rays of radium-E, has led, among other things, to a consideration of the following questions.

1. What proportion of the atoms of an element emitting one or more types of monochromatic γ-rays contributes, on disintegration, to such γ-rays ?
2. Is a knowledge of the wave-lengths and relative intensities of the lines in the spectrum of γ-rays sufficient to enable us to determine effective wave-lengths and, with theoretical aid, to interpret the results of scattering and absorption experiments ?
3. Is the energy of the secondary β-rays which have been called recoil electrons greater than that given by the quantum theory of scattering ?
4. Are the γ-rays of thorium-D always more penetrating than those of radium-C, no matter what the thickness of the absorbing material used ?

I am not prepared to answer questions 3 and 4 and cannot give a complete answer to the other two. The simplest case to examine is radium-D. In the course of his fundamental experiments on the line spectra of γ-rays, Ellis (Proc. Camb. Phil. Soc. 21, p. 121, 1922) has shown that radium-D probably emits "hard" γ-rays of wave-length 0·264 Å.U., part of these rays being absorbed in producing the L and M spectra of radium-D, the "soft" rays, of average wave-length 1·06 Å.U. By a comparison of the total ionisations they produce, I find that the energy of the soft rays $=\frac{1}{2}$ that of the hard rays, and as the energy of a hard ray $=1{\cdot}06/0{\cdot}264$ or 4 times that of a soft ray (if such expressions may be used), it follows that out of every three hard rays emitted by the nuclei of radium-D atoms, two are absorbed in the atoms in which they are produced. The internal atomic absorption coefficient of the hard rays, assuming them to produce the soft rays in the way mentioned, is therefore 0·67 as compared with an external coefficient of about 3×10^{-21}. Ellis and Skinner have directed attention to the very high values of these internal absorption coefficients. It may be worth while pointing out, in connexion with experiments on the scattering of X-rays, that such a high internal coefficient of absorption is not observed with β-rays.

The energy of the unabsorbed hard γ-rays has been found by ionisation measurements to be 1/150 that of the β-rays of radium-E in equilibrium with the radium-D. Taking the average energy of such a β-ray to correspond to 467,000 volts, of a hard γ-ray to 46,700 volts, a simple calculation shows that only one in every five radium-D atoms emits a γ-ray on disintegration. Radium-D apparently does not emit "white" γ-rays or rays which give a continuous spectrum and so we have fairly complete knowledge about it, but this is not the case with most of the other elements emitting γ-rays.

In a recent paper, Ellis (Proc. Camb. Phil. Soc. 22, p. 369, 1924) publishes a table giving some of the lines in the spectrum of the hard γ-rays of radium-C, extending from 0·0453 Å.U. to 0·00557 Å.U. What appears to be the most intense line has a wave-length 0·00867 Å.U., a value not very far from that given above. Such tables, however, even if we knew the relative intensities of the lines, do not enable us to find effective wave-lengths of γ-rays, unless we are certain that only a negligible proportion of the radiation is white. That a large part of the γ-radiation of thorium-D is white, is indicated by the following evidence, to which Ellis (Roy. Soc. Proc. A, 101, p. 1, 1922) has directed attention. The lowest wave-length found by him so far in the line spectrum of these rays is about 0·014 Å.U., and yet they should have a lower average wave-length than the γ-rays of radium-C, as they are more penetrating (see question 4 above), hence the probability of white radiation of very small average wave-length. In the case of radium-C there is not sufficient evidence, so far as I am aware of it, to come to a definite conclusion about the presence or otherwise of white radiation. The following results have been arrived at.

1. If the secondary β-rays, produced in light elements by the hard γ-rays of radium-C, are recoil electrons, with energy given by the quantum theory of scattering (see question 1 above), the effective wave-length of the γ-rays must be much smaller than that usually accepted. Without going into details, I may state that one can prove from this result that no theory, as at present developed, can account for the properties of scattered γ-radiation.
2. With certain reasonable assumptions, it has been found that the internal atomic absorption coefficient of the hard γ-rays of radium-D is 0·67 as compared with an external coefficient of about 3×10^{-21}, and that on disintegrating, one out of every five atoms of radium-D emits a γ-ray.
3. The number of atoms of an element emitting one or more types of monochromatic γ-rays may be only a small fraction of the total number disintegrating and a large part of the γ-ray energy emitted may be due to white radiation.
4. A knowledge of the wave-lengths and relative intensities of the lines in the spectrum of the γ-rays is not, in itself, sufficient to enable one to determine effective wave-lengths, which can be used to interpret the results of experiments on γ-rays.

I think it may fairly be said that it is very difficult to explain the results of experiments on γ-rays of very small wave-length. Definite answers to questions 3 and 4 would help very much. There is not space here to give fully my own opinions, which I must reserve for a communication elsewhere.

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