XXVII. Analysis of the γ rays from the uranium products

H. Richardson M.Sc.

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this by experiment from the third effect to be $1.54 \cdot 10^{-5}$ *.
Hence

$$T = 3 \cdot 10^{-12},$$

which is in good agreement with the value $T = 2 \cdot 10^{-12}$ found from the first effect.

XXVII. *Analysis of the γ Rays from the Uranium Products.*
By H. RICHARDSON, M.Sc., Beyer Fellow, University of Manchester †.

IN previous papers ‡ it has been shown that the γ rays emitted by the radium, thorium, and actinium products can be analysed into groups of different penetrating powers. All the radioactive substances which emit β rays have been examined except the uranium products, viz. uranium X₁ and uranium X₂. In order to complete the series the analysis of the γ rays from these substances has been undertaken, and confirmatory evidence concerning the atomic weight of actinium has been obtained.

The uranium X used in the experiments was separated from 3 kilograms of pure uranium nitrate. The method of separation employed was that used by Soddy and Russell § in their early investigations on the penetrating power of the γ rays from uranium X. It consists in the fractional crystallization of the uranium nitrate from a solution of density 2.06. Under these conditions, the uranium nitrate which crystallizes out only carries with it about one-seventh of the total amount of uranium X present, and the remaining six-sevenths may be poured off with the mother liquor. By repeating this process about three-quarters of the uranium X can be obtained in a solution which contains only a few grams of uranium nitrate. The uranium X was finally separated by precipitation with ammonia and ammonium carbonate in the presence of ferric chloride. By this means the uranium X was obtained together with a small amount of ferric hydroxide, and the whole source thus consisted of

* The value given by Professor Corbino for E is $7.7 \cdot 10^{-5}$. This is to be multiplied by 2 on account of an error corrected in the second of his papers referred to; and it should be divided by 10 since in another place he has used the ampere as the unit of current instead of the absolute unit.

† Communicated by Prof. E. Rutherford, F.R.S.

‡ Rutherford and Richardson, *Phil. Mag.* xxv. p. 722 (1913), xxvi. p. 324 (1913).

§ Soddy and Russell, *Phil. Mag.* xviii. p. 620 (1909).

a very thin layer of material. The purity of the uranium X used was tested by measuring its rate of decay.

As the apparatus and method used in the experiments were the same as those previously employed*, it is not necessary to give details. It may be pointed out, however, that, as the amount of uranium X in equilibrium with one kilogram of uranium nitrate corresponds in γ ray activity to only about .01 mgrm. of radium, the activities obtained were very small and consequently the absorption coefficients could not be measured with great accuracy.

The absorption curves, using aluminium as the absorbing substance, were obtained and analysed in the usual manner.

Fig. 1.

Fig. 1 shows the initial portion of the curve. It will be seen from the figure that about 40 per cent. of the total radiation is absorbed by 2 mm. of aluminium. The absorption, as shown by the logarithm curve, is exponential, the absorption coefficient μ in aluminium being 24 (cm.)⁻¹.

The determination of the absorption curve for greater thicknesses of aluminium was a matter of some difficulty owing to the very small activity (0.3 div. min. initially) at my disposal. It was for this reason impossible to obtain the

* Rutherford and Richardson, *Phil. Mag.* xxvi. p. 324 (1913).

curve for thicknesses of aluminium greater than 5 cm. The numbers obtained over this range clearly indicated, however, that this more penetrating radiation is complex, consisting of two types. This view is supported by the work of Soddy and Russell*, who have previously examined in detail the absorption of the penetrating γ rays from uranium X, using large thicknesses of aluminium. They separated the uranium X from 50 kilograms of uranium nitrate, and with this amount of active material they were able to follow the absorption through 12 cm. of aluminium. Their work was specially directed to determine the absorption coefficient of the residual radiation after passing through 2 cm. of aluminium. They were able to show that after a thickness of 5 cm. the absorption curve was quite exponential. The exact value of the absorption coefficient which they obtained varied slightly according to the particular experimental disposition which they employed. The extreme values of the absorption coefficients in aluminium which they obtained were $\mu = 0.130$ and $\mu = 0.148$. From an inspection of the curves given by Soddy and Russell it is at once seen that a soft type of radiation was also present which was practically absorbed by a thickness of 5 cm. of aluminium. The absorption curve I obtained between 4 mm. and 5 cm. appeared to be in good agreement with the results given by the above curves. I have therefore based the analysis of the absorption curve, shown in fig. 2, on the assumption that the most penetrating type of radiation is that observed by Soddy and Russell. Assuming, with sufficient accuracy, a mean value of the absorption coefficient $\mu = 0.140$, the analysis of the absorption curve between 4 mm. and 5 cm. shows that the other type of radiation has an absorption coefficient $\mu = 0.70$ and that it is exponentially absorbed. As the examination of the absorption of the penetrating γ rays from uranium X had been made with great care by Soddy and Russell, it did not seem necessary in these experiments to repeat any of their work.

It has been shown that uranium X emits γ rays consisting of three types which have absorption coefficients $\mu = 24$, $\mu = 0.70$, and $\mu = 0.140$ in aluminium of density 2.72.

The recent work of Fajans and Göhring†, Hahn and Meitner‡, and Fleck§ has shown conclusively that uranium

* Soddy and Russell, *Phil. Mag.* xviii. p. 620 (1909).

† Fajans and Göhring, *Die Naturwissenschaften*, Heft xiv. p. 339 (1913).

‡ Hahn and Meitner, *Phys. Zeit.* xvi. p. 758 (1913).

§ Fleck, *Phil. Mag.* xxvi. p. 528 (1913).

X is not a simple product but that it consists of two bodies, viz. uranium X_1 and uranium X_2 . Uranium X_1 has a period of 24.6 days and emits soft β rays, and uranium X_2 has a period of 1.1 mins. and emits hard β rays. It is quite impossible

Fig. 2.

without using a very large amount of material to settle definitely to which of the various products the various types of γ rays belong. Evidence on this point may be obtained, however, by a consideration of the penetrating power of the γ rays emitted by radium B, radium C, thorium B, thorium D, actinium B, and actinium D. Previous work has shown that each of the B products emits three types of soft γ rays, whilst radium C, thorium D, and actinium D each emit only one single penetrating type. It has also been pointed out that those bodies which emit soft γ rays also in general emit a soft β radiation.

It would appear therefore reasonable to suppose that uranium X_1 emits those rays for which $\mu = 24$ and $\mu = 0.70$, since these groups correspond to two of the groups emitted

by radium B, thorium B, and actinium B. The single penetrating type of radiation for which $\mu = 0.140$ would then be due to uranium X_2 . Under these conditions the γ rays emitted by uranium X_1 and uranium X_2 would appear to be quite analogous to those emitted by the other members of the radioactive series.

Attention has already been drawn to the fact * that those radiations which correspond to the "L" series of Barkla seem to persist throughout the whole series of radioactive substances, with the exception of the D products. The radiation for which $\mu = 24$ and which appears to be emitted by uranium X_1 evidently belongs to the "L" series. This result gives additional evidence that the atomic weight of actinium is about 230 and that actinium is probably a branch product of the uranium series. Fleck † has already pointed out that the branch cannot come from uranium X_2 . Now previous work has shown that in the case of radium C and thorium B, branch products occur either immediately before or after the emission of a single penetrating type of γ radiation. If we assume that the actinium branch comes from uranium X_1 , then the analogy with the other radioactive bodies would be complete.

Summary.

It has been shown that uranium X, by which are denoted the products uranium X_1 and uranium X_2 in equilibrium, emits three types of γ rays having absorption coefficients in aluminium $\mu = 24$, $\mu = 0.70$, and $\mu = 0.140$ (cm.)⁻¹. Evidence has been given that the first two types are probably emitted by uranium X_1 whilst the third penetrating type is due to uranium X_2 .

The results obtained support also the view that the atomic weight of actinium is about 230 and that actinium is probably a branch product from uranium X_1 .

My best thanks are due to Professor Rutherford for his kind interest and constant help throughout the course of these experiments.

University of Manchester,
December, 1913.

* Rutherford and Richardson, *Phil. Mag.* xxvi. p. 937 (1913).

† Fleck, *Phil. Mag.* xxvi. p. 528 (1913).