



## LXII. The ranges of the $\alpha$ particles from the thorium and actinium products

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calculation of the diffusion coefficient. Hahn and Sackur\* obtained the same value by following the change of activity directly by means of an electrometer. Similarly the period of transformation, 54 seconds or  $\lambda = 1.29 \times 10^{-2} \text{ sec.}^{-1}$  found by Bronson†, was adopted for thorium emanation.

My thanks are due to Professor Rutherford for his help and interest in these experiments.

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LXII. *The Ranges of the  $\alpha$  particles from the Thorium and Actinium Products.* By H. GEIGER, Ph.D., Lecturer in Physics, and J. M. NUTTALL, M.Sc., University of Manchester ‡.

IN two previous papers § we have shown that there exists a quantitative relation between the range of an  $\alpha$  particle and the transformation constant of the product from which it arises. For the products of the uranium-radium series the values of the ranges of the  $\alpha$  particles were partly taken from papers by Bragg ||, and were in part redetermined. As regards the members of the actinium and thorium series, with a few exceptions, only the initial measurements of Hahn¶ were available.

A determination of the ranges of the  $\alpha$  particles from most of the products of these families is difficult, since, owing to the short periods of some of them, it is impossible to separate the products from each other. Thus the actinium emanation and actinium A will always be associated with actinium X, and therefore complicate a determination of the range of the  $\alpha$  particles from the latter substance. Similar difficulties arise in the thorium series.

In the following we have undertaken the redetermination of the ranges of the  $\alpha$  particles emitted by the products of the thorium and actinium series, making use of the experimental arrangement we have previously employed for the determination of the ranges of the  $\alpha$  particles from uranium.

\* Hahn and Sackur, *Ber. deutsch. Chem. Ges.* 38. ii. p. 1943 (1905).

† Bronson, *Amer. Journ. of Sc.* xix. p. 185 (1905).

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

§ H. Geiger and J. M. Nuttall, *Phil. Mag.* xxii. p. 613 (1911); xxiii. p. 439 (1912).

|| W. H. Bragg and R. D. Kleeman, *Phil. Mag.* viii. p. 726 (1904); x. p. 318 (1905).

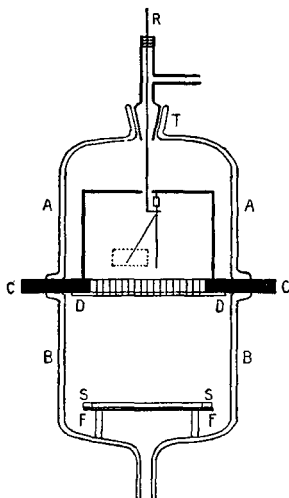
¶ O. Hahn, *Phil. Mag.* xii. p. 244 (1906).

648 Dr. H. Geiger and Mr. J. M. Nuttall on Ranges of

The apparatus, which is slightly modified, is shown again in fig. 1. The main part consists of two large bell jars AA and BB separated by a brass plate CC. A large number of holes—about 250—each 3·7 mm. in diameter and 8 mm. high, forming a circular “grid” of 10 cm. diameter, were drilled through the brass plate CC. An exactly similar but much thinner brass plate DD could be screwed on to the lower side of plate CC. Between these two plates a thin and uniform sheet of mica equivalent in stopping power to 1·1 cm. of air was placed, and fixed down airtight. The lower bell-jar BB contained the active film FF at a distance 22·5 cm. from the mica. On account of the metal grid only the  $\alpha$  particles emitted at angles less than  $20^\circ$  to the normal could pass through the mica into the upper bell-jar, which contained the electroscope. The latter was cylindrical in shape and was 8 cm. high and 10·5 cm. in diameter. It could be charged from outside through the wire R, which could be rotated by means of the ground-glass joint T. In the experiments the upper bell-jar was first completely exhausted and then filled with hydrogen up to a pressure of about 6 cm. of mercury. Hydrogen was used in preference to air, since, according to Taylor\* and others, the rise of the ionization curve is more pronounced in the former gas than in the latter. When filled with hydrogen to 6 cm. pressure the depth of the ionization vessel corresponded to 1·6 mm. of air at atmospheric pressure, since the  $\alpha$  particles had to travel through about 8 cm. in the electroscope before they were stopped by the upper plate. The ionization at different parts of the range of the  $\alpha$  particles could be measured by varying the pressure in the lower bell-jar. In this way the ionization curves for the  $\alpha$  particles from the different products were obtained.

The active materials were again deposited on ground-glass plates in exceedingly thin films. In order to prevent the escape of emanation into the bell-jar BB, which would have completely vitiated the experiments, the active film was covered with a thin and uniform sheet of mica attached to a

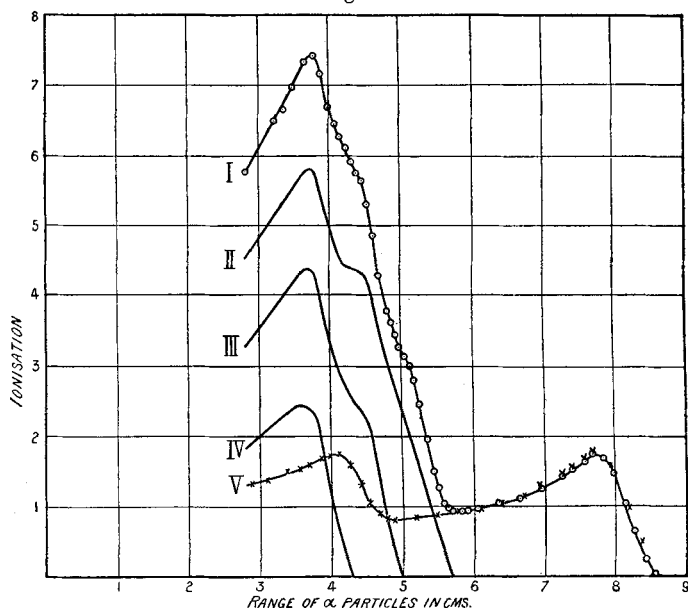
Fig. 1.



\* T. S. Taylor, *Phil. Mag.* xviii. p. 604 (1909); xxi. p. 571 (1911).

ground-glass ring SS; the latter fitted air-tight over a ground-glass plate FF, thus forming a shallow circular box FSSF (see fig. 1), just large enough to hold the active film. A small hole was drilled through the centre of the glass plate FF to allow the gas to escape from the box when the pressure in the bell-jar BB was reduced. Since the glass plate on which the active matter was deposited and the plate forming the base of the box were in close contact no measurable amount of emanation could escape while measurements were taken. On account of the very slow escape of the gas from the box it was necessary to exhaust, and readmit the air, very slowly to prevent breakage of the mica.

Fig. 2.



Curve	I.	= $\alpha$ particles from	Th X, Th Em., Th A, Th C <sub>1</sub> , Th C <sub>2</sub> .
	II.	" "	Th X, Th Em., Th A.
	III.	" "	Th X, Th Em.
	IV.	" "	Th X.
	V.	" "	Th C <sub>1</sub> , Th C <sub>2</sub> .

The thorium X was obtained from radiothorium, and a very thin film of high activity was prepared. Two days were allowed to elapse before measurements were taken, so that the active deposit might attain equilibrium with the thorium X. The ionization curve was then determined as described above, and is shown by Curve I. of fig. 2. To deduce the ranges of the products composing Curve I.,

Curve V. was first subtracted which represented the ionization produced by the  $\alpha$  particles of the active deposit of thorium. This latter curve was obtained by a separate experiment, the results of which are represented by the crosses of Curve V. The difference curve, shown in Curve II., represents the ionization curve of the  $\alpha$  particles from thorium X, thorium emanation, and thorium A. It was now necessary to analyse this latter curve into its three parts, due to the three types of  $\alpha$  particles named above. This could be done by subtracting from Curve II. the ionization curve of a simple  $\alpha$  ray product taken under exactly the same conditions. The accurate shape of the ionization curve of a simple  $\alpha$  ray product could be taken from the long-range  $\alpha$  particles of thorium C<sub>2</sub> from either of Curves I. or V. It had, however, to be borne in mind that the number of  $\alpha$  particles from thorium C<sub>2</sub> is not the same as that from the other products. As Marsden and Barratt\* have shown, thorium C<sub>1</sub> emits 35  $\alpha$  particles and thorium C<sub>2</sub> 65  $\alpha$  particles for a hundred disintegrating atoms of thorium emanation. Moreover, on account of the fact that the period of thorium B is of the same order of magnitude as that of thorium X, there does not exist true radioactive equilibrium between these substances. Thorium B and the succeeding products will be present in excess of their true equilibrium values. From a simple calculation it is easy to show that the excess of thorium B over thorium X amounts to about 12 per cent.† On the other hand, thorium X, thorium emanation, and thorium A are for practical purposes in true radioactive equilibrium, *i. e.*, they emit the same number of  $\alpha$  particles per second. By multiplying the ordinates of the end portion of Curve V. by the two factors  $\frac{100}{65}$  and  $\frac{88}{100}$  an ionization curve is obtained which, except for the range, must be identical with the curve for the separate  $\alpha$  particles from thorium X, thorium emanation, or thorium A. This curve was subtracted twice from Curve II., making the ends of the ranges coincide in each case. The result of the first subtraction is shown in Curve III., giving the range of the thorium emanation. After the second subtraction, Curve IV. is obtained, which gives the range of the  $\alpha$  particle from thorium X. Hence, finally, the horizontal distances from the origin at which the Curves II., III., IV. cut the axis of abscissæ give the ranges of the  $\alpha$  particles from thorium A, thorium emanation, and thorium X respectively. The ranges

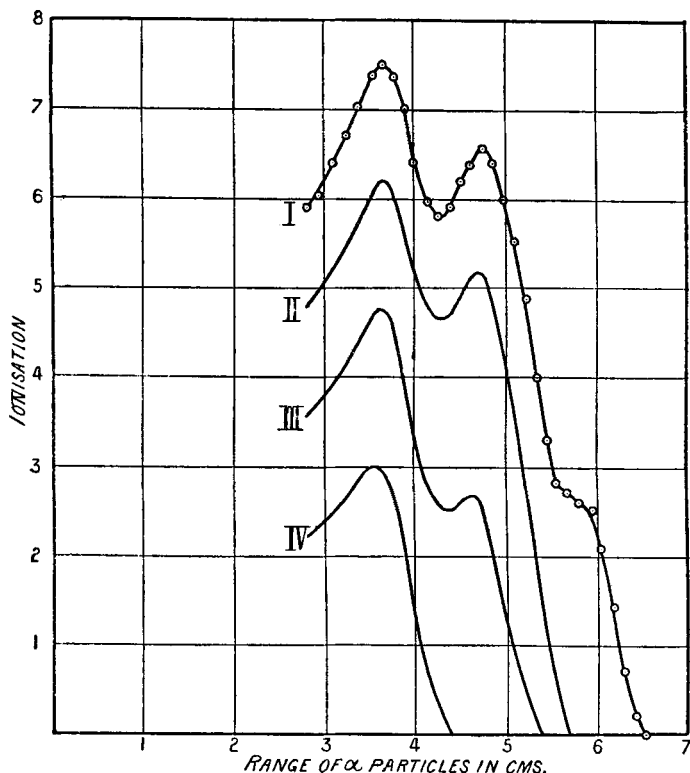
\* E. Marsden and T. Barratt, Proc. Phys. Soc. xxiv. p. 50 (1911).

† Rutherford and Chadwick, Proc. Phys. Soc. xxiv. p. 141 (1912).

*$\alpha$  particles from Thorium and Actinium Products.* 651

are all compared with the range of thorium  $C_2$  as standard (8.60 cm. at  $15^\circ \text{C}$ ). The ranges are tabulated in the table at the end of the paper, and are in fair agreement with the figures given by Hahn\* and by Barratt†. The range of thorium X, which has not been determined before, was found to be 4.30 cm. at  $15^\circ \text{C}$ .

Fig. 3.



Curve I. =  $\alpha$  particles from Act X, Act C, Act Em, Act A.

II. " " Act X, Act C, Act Em.

III. " " Act X, Act C.

IV. " " Act X.

Similar experiments were carried out with actinium X, under exactly the same conditions as described above in the case of thorium X. A very thin film of actinium X of sufficient activity was prepared. Curve I. of fig. 3 shows the

\* O. Hahn, *Phil. Mag.* xii. p. 82 (1906).

† T. Barratt, *Proc. Phys. Soc.* xxiv. p. 112 (1912).

experimental results, and gives the ionization curve of the  $\alpha$  particles from actinium X, actinium C, actinium emanation, and actinium A. Since in this case there is no substance giving  $\alpha$  particles of prominent range, it was more difficult to obtain the ranges of the different products by subtraction. The standard ionization curve was fitted on to the end of Curve I. (of fig. 3), so that the maximum coincided with the inflexion in Curve I. After subtracting the standard curve three times in succession, the ionization Curves II., III., IV. were obtained. Curve II. gives the ionization curve due to actinium X, actinium C, and actinium emanation; Curve III. that due to actinium X and actinium C; and Curve IV. that of actinium X. The Curve IV. finally remaining was slightly higher than the standard curve, but this deviation was probably within the experimental error. Since the period of actinium X is long compared with the periods of the succeeding products, no correction had to be made for the deviation from true equilibrium.

The ranges obtained from fig. 3 and given later in Table I. are in satisfactory agreement with the measurements taken previously by one of us\* by the scintillation method, and also with those obtained by Hahn† by Bragg's method.

In our previous discussion of the ranges of the  $\alpha$  particles from the actinium products we have taken for the range of the  $\alpha$  particles from radioactinium the value obtained by Hahn, which is 4.80 cm., and slightly greater than that of actinium X. This result appears to be an exception to the relation we have given between range and period, since the  $\alpha$  particles from actinium X, which has the shorter life, should have the longer range.

To decide whether this was actually an exception to the rule we have carried out experiments under exactly the same conditions with a film of radioactinium. This was prepared according to the method given by Hahn, and was at the time of measurement practically free from all subsequent products. The curve obtained indicated a value for the range little different from that found by Hahn, and showed that the  $\alpha$  particles from radioactinium had actually a range somewhat longer than those from actinium X. The deviation from the range-period rule is perhaps only apparent, since it seems quite possible that radioactinium consists of two products, one of which emits  $\beta$  rays and has the period of about 19.5 days, and one which has a considerably shorter life and emits the  $\alpha$  rays. Some preliminary

\* H. Geiger, *Phil. Mag.* xxi. p. 201 (1911).

† O. Hahn, *Phil. Mag.* xii. p. 244 (1906).

*$\alpha$  particles from Thorium and Actinium Products.* 653

experiments to effect a separation have, however, so far been unsuccessful.

The following table gives the values of all the ranges of the  $\alpha$  particles which have been given by us in this and previous papers. The values for radium emanation, radium A, and radium C are those given by Bragg and Kleeman. The ranges are given for the temperatures  $0^{\circ}$  C. and  $15^{\circ}$  C, and for convenience the initial velocities of expulsion of the  $\alpha$  particles are added. The velocities  $v$  are calculated from the equation  $v^3 = aR$ , where  $R$  denotes the range of the  $\alpha$  particles and  $a$  is a constant\*. The initial velocity of the  $\alpha$  particles from radium C is taken as  $2.06 \times 10^9 \frac{\text{cm.}}{\text{sec.}}$  †.

Ranges of  $\alpha$  particles.

Substance.	Ranges at		Initial velocity.
	$0^{\circ}$ C.	$15^{\circ}$ C.	
Uranium 1 .....	2.37 cm.	2.50 cm.	$1.47 \times 10^9 \frac{\text{cm.}}{\text{sec.}}$
Uranium 2 .....	2.75	2.90	1.54
Ionium .....	2.85	3.00	1.56
Radium.....	3.13	3.30	1.61
Ra Emanation .....	3.94	4.16	1.74
Radium A.....	4.50	4.75	1.82
Radium C.....	6.57	5.94	2.06
Radium F.....	3.58	3.77	1.68
Thorium .....	2.58	2.72	1.51
Radiothorium .....	3.67	3.87	1.70
Thorium X .....	4.08	4.30	1.75
Th. Emanation.....	4.74	5.00	1.85
Thorium A .....	5.40	5.70	1.93
Thorium C <sub>1</sub> .....	4.55	4.80	1.82
Thorium C <sub>2</sub> .....	8.16	8.60	2.21
Radioactinium.....	4.36	4.60	1.80
Actinium X .....	4.17	4.40	1.77
Act. Emanation .....	5.40	5.70	1.93
Actinium A .....	6.16	6.50	2.02
Actinium C .....	5.12	5.40	1.89

In fig. 4 (p. 654) the logarithms of the transformation constants of the products are plotted against the logarithms of the ranges of the  $\alpha$  particles. The relations for the uranium-radium and the actinium series have been given before, and are repeated with very slight changes. The points representing the products of the thorium series also lie approximately on a straight line which falls between and is parallel

\* H. Geiger, Proc. Roy. Soc. A. lxxxiii. p. 506 (1910).

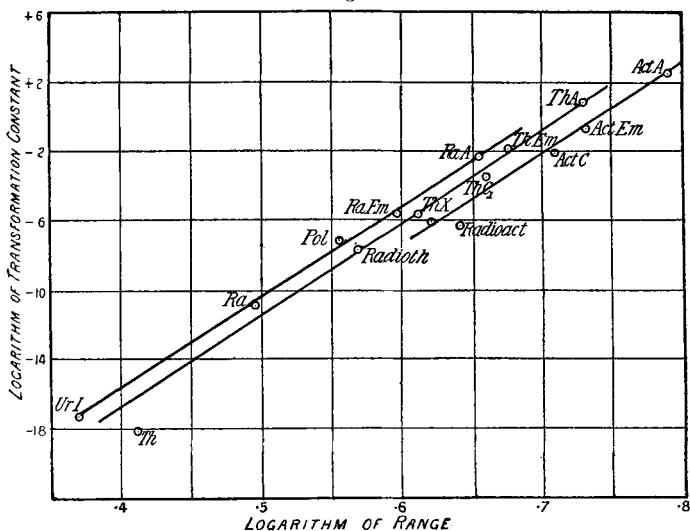
† E. Rutherford, Phil. Mag. xii. p. 348 (1906).



# 654 *Ranges of $\alpha$ particles from Thorium and Actinium.*

to, the corresponding lines for the radium and actinium series.

Fig. 4.



The range of the  $\alpha$  particles from thorium itself is somewhat longer than should be expected from the rule, but it must be remembered that this range is by far the most difficult to determine, since the activity from thorium alone is only about one-fifth of that from uranium. The deviation in this case may therefore be within the experimental error, and the only product which is not in agreement with the range-period rule is, as stated above, radioactinium, but there seems to be the possibility that this product has not the period which is usually attributed to it.

On account of the uncertainty of their periods the products uranium 2, ionium, radium C, and thorium  $C_2$  are not entered on fig. 4. From the straight line relation it follows that uranium 2 should have a period about  $2 \times 10^6$  years and ionium a period of about 200,000 years. The latter figure is of the same order as the approximate value given by Soddy\*, namely, 132,000 years. The periods of radium C and thorium  $C_2$  should be about  $10^{-6}$  second and  $10^{-11}$  second respectively.

We wish to express our thanks to Prof. Rutherford for his kind interest in these experiments.

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\* F. Soddy, *Le Radium*, vii, p. 295 (1910).