Philosophical Magazine Series 6

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tphm17

LVII. The ranges of the α particles from various radioactive substances and a relation between range and period of transformation

H. Geiger Ph.D. [a] & J.M. Nuttall B.Sc. [a]

[a] Physical Laboratories , The Victoria University , Manchester

Published online: 20 Apr 2009.

To cite this article: H. Geiger Ph.D. & J.M. Nuttall B.Sc. (1911) LVII. The ranges of the α particles from various radioactive substances and a relation between range and period of transformation , Philosophical Magazine Series 6, 22:130, 613-621, DOI: 10.1080/14786441008637156

To link to this article: http://dx.doi.org/10.1080/14786441008637156

types of rays. On the basis of this assumption the whole number of ions produced by a β particle of high speed per cm. of its path at atmospheric pressure is 67.

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

Physical Laboratories.
The Victoria University, Manchester.

LVII. *The Ranges of the α particles from Various Radioactive Substances and a Relation between Range and Period of Transformation.* *By* H. GEIGER, *Ph.D.*, *and* J. M. NUTTALL, *B Sc.*, *University of Manchester* *.

IT is well known that the α particles from different radioactive substances are characterized by their ranges, *i. e.* by the distance through which they can travel in air at atmospheric pressure. This was first pointed out by Bragg, and the ranges of a number of products have been determined by him and his co-workers. The method applied by Bragg to determine the ranges is well known. By means of a set of parallel tubes placed directly above the active plate α rays with practically parallel paths were obtained. The ionization produced by these rays was measured at different distances in a shallow ionization vessel, and the distance in air at which the ionization just disappeared was taken as the range of the α particles.

It was shown by Rutherford that at the same distance from the source at which the α particles fail to produce ionization they also lose their power of producing scintillations. The observation of the scintillations at different distances from the source therefore presents another way of determining the ranges of the α particles, and this method has frequently been made use of by Hahn and other observers. It appears, however, that the scintillations method gives somewhat smaller values for the ranges than the ionization method.

Great difficulty has been experienced in the determination of the ranges of the very inactive substances uranium and thorium. In these cases, the methods mentioned above are not applicable. Estimates of the ranges of these products were, however, made by Bragg †, but more accurate values

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

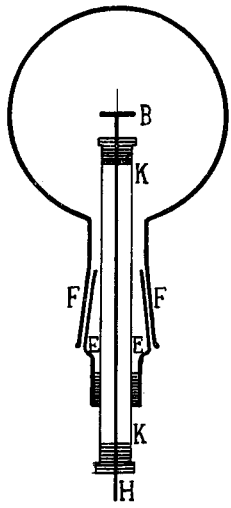
† W. H. Bragg, Phil. Mag. xi. p. 754 (1906).

—in the case of uranium—have recently been given by Geiger and Rutherford*, and by Foch†.

It would be of great importance if a method could be devised which would be equally suitable for the accurate determination of the ranges of all the known α ray products, but at present no such method has been found. The main difficulties result from the fact that some of the products are gases, whilst some are very feebly active or only available in the presence of other α ray products.

In the present investigation we have employed a method which appears specially suitable for the determination of the ranges of the substances whose activities are small. The arrangement is indicated in fig. 1. The inside of a large glass bulb is silvered and connected to a battery of about 700 volts. The active film is placed in the centre of the bulb on a small metal disk B which is connected to the electrometer by means of the wire H. The brass tube KK surrounding the wire, and insulated from it by ebonite plugs, serves as electrostatic protection, and prevents any electrical leak from the glass bulb to the wire. The tube passes air-tight through the ground-glass joint E, which fits into the corresponding part F, sealed to the glass bulb. The length of the wire H is carefully adjusted so that the plate B is exactly in the centre of the bulb. If the pressure in the bulb is reduced the ionization produced by the α particles will remain practically constant so long as the range of the α particles at the particular pressure does not exceed the radius of the bulb, viz. 7·95 cm. But as soon as the pressure is decreased below that value the ionization current will also decrease. From this critical pressure and the radius of the bulb the range of the α particles can easily be deduced. It adds greatly to the accuracy of the determination of the critical pressure if the active layer is very thin, and if the area over which it is spread is small. Experiments with polonium showed that plates with diameters up to 2·6 cm. could be used without introducing an appreciable error.

Fig. 1.

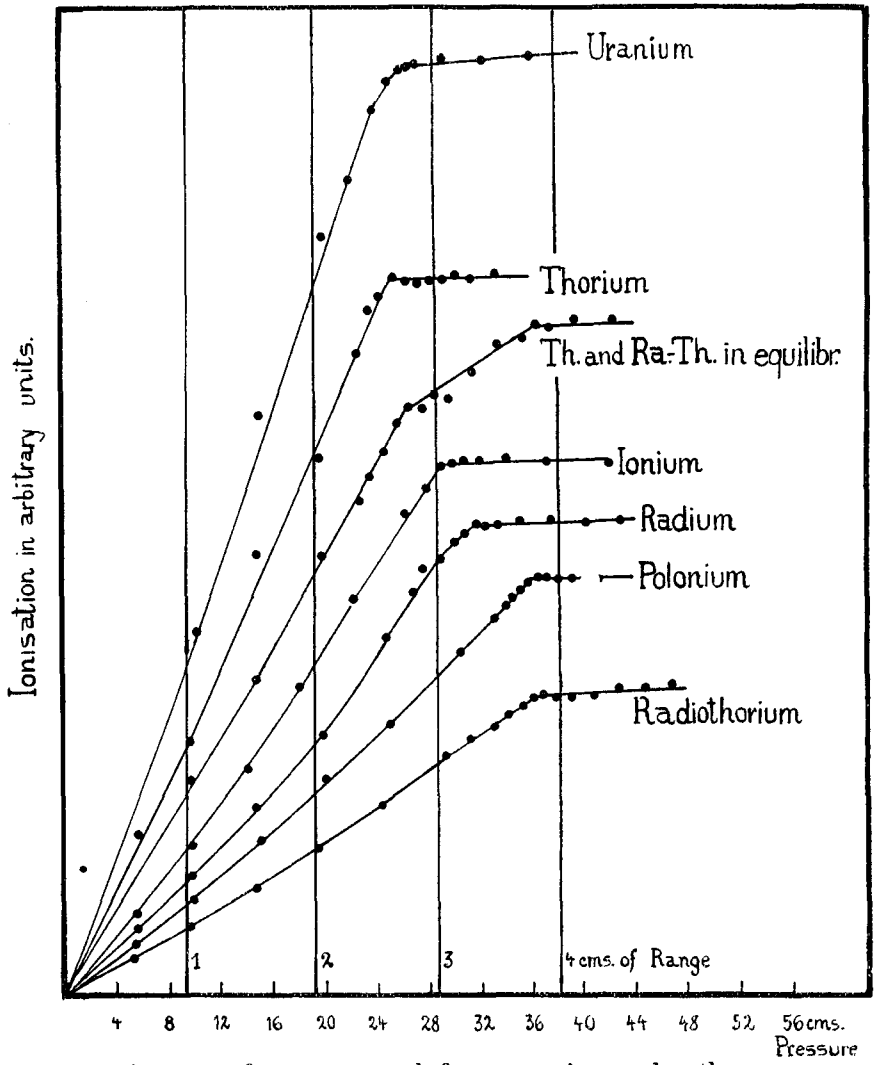


* H. Geiger and E. Rutherford, *Le Radium*, vii. p. 225 (1910), and Phil. Mag. xx. p. 691 (1910).

† A. Foch, *Le Radium*, viii. p. 101 (1911).

In fig. 2 the curves for air obtained with different substances are given. The abscissæ give the pressure in

Fig. 2.



centimetres of mercury, and for convenience also the corresponding ranges reduced to 76 cm. pressure and 15° centigrade are marked. The ordinates give the ionization current measured by the electrometer for each particular

pressure. It will be seen that the critical pressure is sharply defined in each case.

A few details regarding the radioactive substances used in these experiments may be given.

1. *Uranium.*—3 mgr. of uranium oxide were spread uniformly over an area of 2·5 cm. diameter. Experiments made with thicker films gave practically the same result.

2. *Thorium.*—It is well known that thorium cannot be separated from radiothorium. Through the kindness of Prof. Boltwood we have, however, obtained some thorium which, on account of frequent precipitations over a period of many years, was repeatedly freed from mesothorium, and thus the radiothorium had practically died away. Immediately before the measurements were taken the thorium was precipitated several times in order to get rid of the thorium X and the subsequent products which might have been present.

3. *Thorium and Radiothorium in equilibrium.*—Some thorium with the radiothorium in equilibrium was separated from thorite mineral, and by several precipitations freed from thorium X and the following products. The curve shows two distinct breaks corresponding to the α rays from thorium and radiothorium.

4. *Ionium.*—The source consisted of a small and hardly visible spot of ionium mixed with thorium on a thin aluminium-foil. The activity due to the thorium was too small to be detected.

5. *Radium.*—A radium solution was first freed from polonium, emanation, and active deposit. A drop of the solution was evaporated on a platinum plate and the measurements taken immediately.

6. *Polonium.*—The polonium films were prepared by bringing the polonium solution in contact with a carefully cleaned copper-foil. By electrolytic action the polonium is then deposited on the copper-foil.

7. *Radiothorium.*—Radiothorium was separated from a mesothorium preparation and freed from thorium X and the following products. A thin film was prepared and measurements taken at once.

The results for the different products employed in these measurements are collected in the following table. In each case the average value of all the measurements is given and reduced to a pressure of 76 cm. and a temperature of 15° and 0° centigrade respectively. But it must be remembered that recent investigations have shown that actually only a small fraction of the α particles traverses the whole range,

and that on account of scattering and possibly other causes many are stopped at a somewhat shorter distance. One of us* has shown that the velocity of expulsion of the α particles is proportional to the cube root of its maximum range. Thus, knowing the velocity of one product the velocities of the others can be deduced. Comparison is most suitably made with Ra C, for which the initial velocity has been measured by Rutherford† and was found to be $2{\cdot}06 \times 10^9$ cm./sec. The initial velocities of expulsion calculated in this way are added in the table.

Substance.	Range 15° C.	Range 0° C.	Initial Velocity of Expulsion.
Uranium	2·72 cm.	2·58 cm.	$1{\cdot}51 \times 10^9$ cm./sec.
Ionium	3·00 „	2·84 „	$1{\cdot}56 \times 10^9$ „
Radium	3·30 „	3·13 „	$1{\cdot}61 \times 10^9$ „
Polonium	3·77 „	3·58 „	$1{\cdot}68 \times 10^9$ „
Thorium	2·72 „	2·58 „	$1{\cdot}51 \times 10^9$ „
Radiothorium ...	3·87 „	3·67 „	$1{\cdot}70 \times 10^9$ „

We have already mentioned the earlier estimates of the ranges of uranium and thorium. The range of ionium has been measured by Boltwood‡, that of radium by Bragg and Kleeman§, that of polonium by Kucera and Masek‖, and by Levin¶, and that of radiothorium by Hahn**. Nearly all the figures given in the table above are in fair agreement with those obtained by previous observers. In some cases, however, pressure and temperature of the air are not mentioned, so that it is difficult to make a comparison of value between the present and older determinations.

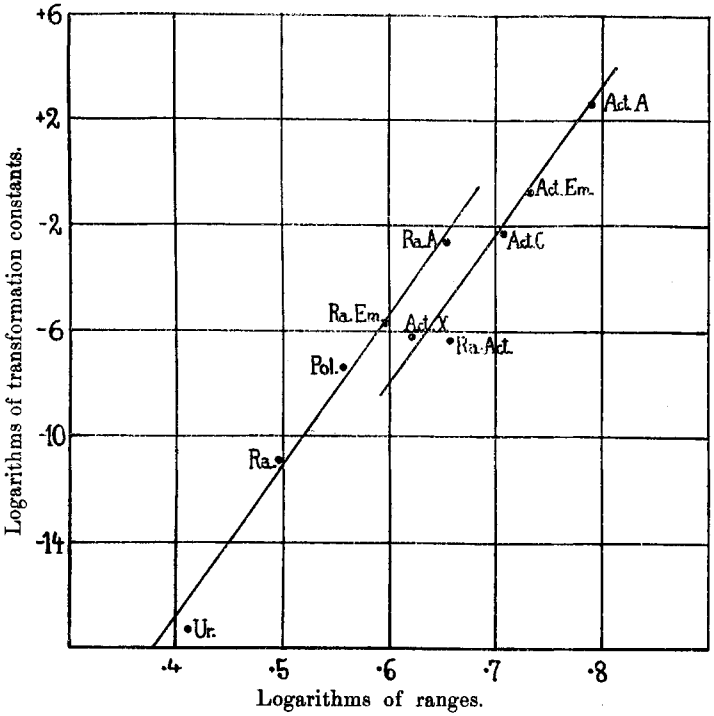
In connexion with the redetermination of the ranges of the α particles from a number of products, given above and in a previous paper by one of us††, we have reconsidered the possibility of a relation between the period of the active substances and the ranges of the α particles emitted by them.

* H. Geiger, Proc. Roy. Soc. A. lxxxiii. p. 505 (1910).
† E. Rutherford, Phil. Mag. xii. p. 348 (1906).
‡ B. B. Boltwood, Amer. Journ. Sc. xxv. p. 365 (1908).
§ W. H. Bragg and R. D. Kleeman, Phil. Mag. x. p. 318 (1905).
‖ Kucera and Masek, *Phys. Zeitschr.* vii. p. 337 (1906).
¶ M. Levin, *Phys. Zeitschr.* vii. p. 519 (1906).
** O. Hahn, *Phys. Zeitschr.* vii. p. 456 (1906).
†† H. Geiger, Phil. Mag. xxii. p. 201 (1911).

It has been already pointed out by Rutherford * in 1907 that possibly a relation exists between these quantities. It appeared that the range of the α particles was greater the smaller the period of transformation of the substance. There were, however, several products for which this relation did not seem to hold.

In order to find any possible relation between the range and the period we have plotted in fig. 3 the logarithms of

Fig. 3.



the transformation constants of the different products against the logarithms of the corresponding ranges for the products in the uranium-radium series and in the actinium series. The data from which these curves are plotted are given in the following table. For convenience the initial velocity of expulsion is added as well as the half-value period and the transformation constant. The ranges are reduced to 0° centigrade.

* E. Rutherford, Phil. Mag. xiii. p. 110 (1907).

Substance.	Range at 0°.	Initial Velocity.	Transformation Constant.	Half-value Period.
Uranium	2·58 cms.	$1·51\times10^{9}$ cm./sec.	$4·6\times10^{-18}$	5×10^{9} years
Ionium	2·84 „	1·56 „ „	———	———
Radium	3·13 „	1·61 „ „	$1·1\times10^{-11}$	2000 years
Ra Emanation ...	3·94 „	1·74 „ „	$2·085\times10^{-6}$	3·85 days
Radium A	4·50 „	1·81 „ „	$3·85\times10^{-3}$	3·0 minutes
Radium C	6·57 „	2·06 „ „	———	———
Polonium	3·58 „	1·68 „ „	$5·60\times10^{-8}$	143 days
Radioactinium ...	4·55 „	1·82 „ „	$4·1\times10^{-7}$	19·5 days
Actinium X	4·17 „	1·77 „ „	$7·6\times10^{-7}$	10·5 days
Act Emanation ...	5·40 „	1·93 „ „	$1·8\times10^{-1}$	3·9 seconds
Actinium A	6·16 „	2·02 „ „	350	$\frac{1}{350}$ second
Actinium C	5·12 „	1·90 „ „	$5·4\times10^{-3}$	2·15 minutes

All the products in the uranium-radium series are marked on the curve except ionium and radium C. In the case of ionium the period has not yet been determined, but according to Soddy* it is between 5×10^{4} and 10^{6} years. It will be seen that the numbers of the uranium-radium series lie very closely on a straight line. Assuming that ionium is no exception to the rule, and taking the range of its α particles to be 2·84 cm., an inspection of the curve shows that its half-value period should be nearly as high as one million years.

The discussion of radium C presents some difficulties, for from its range the half-value period of the product should be exceedingly short, about 10^{-6} second. The recent work of Hahn and Meitner† and of Fajans‡ has shown that the substance ordinarily called radium C is undoubtedly complex, and that the changes occurring in these substances are perhaps irregular. There is certainly no definite evidence yet available which would contradict the possibility that the period of transformation of the product which gives rise to the long-range α particles is very short.

It should be pointed out that a certain difficulty exists with regard to uranium. Boltwood§ has shown that the change in uranium gives rise to two α particles for one in each of the successive products, and this has been confirmed

* F. Soddy, *Le Radium*, vii. p. 295 (1910).
† O. Hahn and L. Meitner, *Phys. Zeitschr.* x. p. 697 (1909).
‡ K. Fajans, *Phys. Zeitschr.* xii. p. 369 (1911).
§ B. B. Boltwood, Amer. Journ. of Sci. xxv. p. 269 (1908).

by the scintillation method by Geiger and Rutherford*. This may be ascribed to the existence of two successive α-ray products, or to the emission of two α particles in the disintegration of each atom. This latter hypothesis is excluded by the experiments of Marsden and Barratt†, who found no evidence that two α particles were emitted simultaneously. In regard to the first supposition Marsden and Barratt's work also indicates that the period of the second product is more than a few seconds. It seems not impossible that there may exist two successive products, each of long period, which cannot be separated by ordinary chemical methods. For example, if the periods of these two substances were of the same order of magnitude the ranges of the α particles would differ very little and therefore be difficult to distinguish.

In regard to actinium, it will be observed that the previous notation has been changed in consequence of the discovery of a new α-ray product following the emanation. The new product is called actinium A, the second product actinium B, &c. The reason for the change of nomenclature is given in the following paper by Rutherford and Geiger. It will be seen from the figure that the relation between range and period is again represented by a straight line falling below the corresponding line of the uranium-radium series. Radio-actinium does not lie exactly on the line; this may be due to a slight error in the range, which is in this case difficult to determine.

The nomenclature for the active deposit of the thorium emanation has also been changed in a similar manner to that of actinium in consequence of the discovery of another quickly decaying α-ray product, but the ranges of this product and of the emanation have not yet been determined with accuracy. Some preliminary experiments, however, made by one of us indicated that the numbers referring to the products of the thorium series also lie on a straight line when plotted in the same way as has been done for the uranium-radium and actinium series. The details will be discussed later when some experiments now in progress have been completed.

The connexion indicated above between the period and range is at present only empirical, but it may depend on some simple relation which may ultimately be brought to light. Similar straight lines to those above would be obtained by plotting period against initial velocity of expulsion, since the range is proportional to the third power of the velocity.

It is of interest that the relation discussed above offers a

* H. Geiger and E. Rutherford, Phil. Mag. xx. p. 691 (1910).

† E. Marsden and J. Barratt, Proc. Phys. Soc. xxiii. p. 367 (1911).

possible explanation of the reason why no substance has been found emitting α rays of range shorter than 2·58 cm. For example, the life of a substance which emitted α rays of range 1 cm. would be so long, and consequently its transformation so slow, that its activity would be beyond the limits of detection by present methods.

Experiments are at present in progress with the view of determining with accuracy the ranges of the products which are yet uncertain. The result of such a complete investigation may be expected to show definitely whether the relation given holds generally for all the substances emittting α rays.

We are indebted to Prof. Rutherford for his help and his interest in these experiments.

The Victoria University, Manchester,
Physical Laboratories.

LVIII. *Transformation and Nomenclature of the Radioactive Emanations.* *By* Prof. E. RUTHERFORD, *F.R.S.*, *and* Dr. H. GEIGER, *University of Manchester* *.

IN a recent paper, H. Geiger * has described experiments which show that the emanation of actinium contains a product of very quick transformation, which emits α rays of long range, 6·5 cm. in air, while the range of the α particles from the emanation itself is 5·7 cm. Immediately after its formation, this new substance has a positive charge, and travels to the negative electrode in an electric field. By assuming that this positive carrier has the same mobility in air as a positive ion produced in air, it was deduced that the quick product was half transformed in about 1/500 of a second. The proof of the existence of this product at once explained the observation made some time before by Geiger and Marsden that the emanation of actinium apparently emitted two α ray particles at nearly the same time. Since the new product is almost completely transformed in 1/50 of a second after its formation, the α ray particle from the emanation itself would be followed within this interval by one from the new product, and the interval between them could not be detected by the eye using the scintillation method. In a previous paper, Geiger and Marsden † have also shown that the emanation of thorium emits two α particles in rapid succession. In this case there was on the average a distinct interval between the appearance of two scintillations on the zinc sulphide screen, indicating

* Communicated by the Authors.
† Phil. Mag. July 1911. ‡ *Phys. Zeit.* xi. p. 7 (1910).