



LXXXVI. Radium D and its products of transformation

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To cite this article: G.N. Antonoff (1910) LXXXVI. Radium D and its products of transformation , Philosophical Magazine Series 6, 19:114, 825-839, DOI: [10.1080/14786440608636863](https://doi.org/10.1080/14786440608636863)

To link to this article: <http://dx.doi.org/10.1080/14786440608636863>



Published online: 21 Apr 2009.



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THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[SIXTH SERIES.]

JUNE 1910.

LXXXVI. *Radium D and its Products of Transformation.*

By G. N. ANTONOFF*.

WHEN the activity of a body which has been exposed to the radium emanation for some time is measured, it is found that after the initial products, radium A, radium B, and radium C, have disappeared, there still remains a residual activity. This was first noticed by Mme. Curie and examined in detail by Rutherford†, who found that the active matter was complex and consisted of at least three successive products which he called radium D, radium E, and radium F. Radium D was found to be a rayless product of long period of transformation (the "period" being the time taken for a product to be half transformed), radium E a β -ray product with a period of about six days, and radium F an α -ray product with a period of about 140 days. It is now definitely known that the polonium of Mme. Curie is identical with radium F, and that the primary source of activity in radio-lead separated from radioactive minerals is radium D. Rutherford's results were extended and completed by Meyer and v. Schweidler‡, who examined in particular the products of radio-lead, and showed that they were identical with radium D, radium E, and radium F. By comparison of the β -ray activity of radium E and radium C, Rutherford§

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

† Phil. Mag. viii. p. 636 (1904); x. p. 291 (1905).

‡ Wien. Ber. cxv. Abt. ii a, May 1906.

§ 'Radioactivity,' 2nd edition, p. 405 (1903).

deduced the period of transformation of radium D, which he found to be about 40 years; while by comparison of the α -ray activity of radium F with that of radium C, Meyer and v. Schweidler* obtained the value 12 years. In the latter experiments a correction was made for the difference in ionizing power of the α particles from radium C and radium F. Data are not yet available for the corresponding correction due to the difference in speed of the β particles from radium C and radium E.

As it is now a matter of importance to know the period of transformation of these products with accuracy, the period of radium D has been determined by a new method, and the question as to whether there are two products between radium D and radium F has been closely examined. From experiments on the initial rise of the β ray activity of radium D, Rutherford† found the time period of radium E to be 6 days, while the period of decay of radium E, from which most of the radium D had been driven by heating, was found to be 4.5 days. Meyer and v. Schweidler found that a preparation of radium E lost its β -ray activity initially according to a period of 4.8 days, but finally decayed more slowly according to a period of 6.2 days. They suggested as an explanation of their own and Rutherford's experiments that there are two products between radium D and radium F, and that the first is rayless, and has a period of 6.2 days, while the second is a β -ray product, and has a period of 4.8 days‡. The following experiments were made with the view of settling definitely whether or not there are two products.

Experiments with Radium E.

Suppose that radium E is complex and consists of two successive products, E_1 which is rayless and E_2 which emits β rays. Then, if radium E_1 is completely separated from the mixture of radium D and radium E_1 and E_2 , the β -ray activity of radium E_2 will decrease exponentially with its characteristic period. Similarly radium D will recover its β -ray activity according to the same period. If, however, radium E_1 and radium E_2 are separated together, the β -ray

* *Wien. Ber.* cxvi. Abt. ii a, April 1907.

† *Loc. cit.*

‡ H. W. Schmidt, *Phys. Zeit.* viii. p. 365 (1907). Also Meyer and v. Schweidler, *Phys. Zeit.* viii. p. 457 (1907). Also H. Hess, *Wien. Ber.* cxvi. II. p. 1289 (1907).

activity of the two will obviously not decrease according to an exponential law at first, since radium E_1 is changing to radium E_2 . Finally, however, the decay will be exponential, corresponding to the slower of the two periods. In the experiments described later, the β -ray product has been separated from radium D, and has been found to decay always according to an exponential law, with a period of 5 days, and *only* 5 days. At the same time the radium D, inactive immediately after the separation, recovers its β -ray activity according to the same period; consequently if radium E_1 exist it must always have remained with radium D in equilibrium amount, while radium E_2 must have been completely separated. It is therefore impossible to disprove the existence of radium E_1 by such an experiment. The question of its existence can, however, be definitely settled by another method, depending on the observation of the rise of the β -ray activity in a preparation of initially pure radium D. To this end the following experiment was made:—A piece of platinum foil was exposed to the emanation corresponding to the equilibrium amount of 150 milligrams of radium bromide. The quantity of emanation being very large it was sufficient, in order to obtain a strong enough preparation of radium D, to expose for 24 hours only. The emanation occluded by the platinum was got rid of by dissolving the active deposit in acid and evaporating on a watch-glass. The active deposit of short period decays in a few hours, and we have practically pure radium D left, with only a very small β -ray activity. The curve showing the recovery of the β -ray activity was very carefully determined until a maximum value was reached. This curve was found to be identical with the other recovery curves, being exponential, and showing a period of 5 days. The results are given in the following Table I., where the maximum activity (that after 40 days) is taken as 100. If the rise of the activity is due to the production of a single β -ray product the recovery curve of the activity is given by the equation

$$\frac{I}{I_0} = 1 - e^{-\lambda t},$$

where I_0 is the maximum activity and I is the activity at any time t . The theoretical numbers calculated for a period of 5 days are given in column B of Table I. They show a very good agreement with the experimental values given in

column A. This is shown in fig. 1, where curve 1 represents the theoretical values, and the points represent the experimental values. If the recovery is due to the formation of successive products radium E₁ and E₂, which have constants λ_1 and λ_2 , and of which only the latter emits β -rays, it can easily be shown that the activity I at any time t is given by

$$\frac{I}{I_0} = \left(1 - \frac{\lambda_1 e^{-\lambda_2 t} - \lambda_2 e^{-\lambda_1 t}}{\lambda_1 - \lambda_2}\right),$$

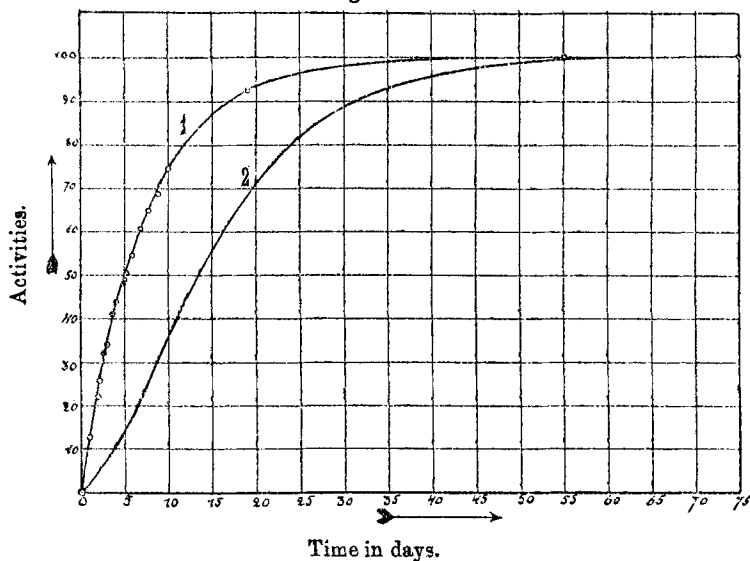
where I_0 is the maximum value. Taking Meyer and v. Schweidler's suggested periods for radium E₁ and radium E₂, viz. 4.8 and 6.2 days respectively, the activity at any time is given in column C, and is shown in curve 2 of fig. 1. The difference between this curve and the previous one is so striking that it is impossible to confuse them. It may be remarked that in the first case the activity after 5 days is 50 per cent. of the maximum, while in the latter it is only 14 per cent. This experiment shows conclusively that only one product exists between radium D and radium F, and that this product emits β rays.

TABLE I.

Time in Days.	Activities in arbitrary units, final value taken=100.		
	A. Experimental.	B. Theoretical for one product radium E with period 5 days.	C. Theoretical for two products radium E ₁ and E ₂ with periods 4.8 and 6.2 days resp.
0	0	0	0
1.04	13.3	13.4	2.2
1.9	22.4	23.1	4.8
2.2	26.4	26.3	5.6
2.8	31.9	32.2	7.0
3.8	41.2	41.3	10.1
4.8	48.3	48.6	14.2
4.9	49.2	49.3	14.9
5.1	50.7	50.3	15.0
5.8	54.6	55.2	18.5
6.8	60.4	61.0	22.5
7.8	65.7	66.1	26.0
8.8	68.6	70.5	30.2
9.9	74.4	74.6	35.0
19	92.5	92.8	69.0
55	100	100	99
115	100	100	100

Some other experiments on the decay of radium E will now be described. Some radium E was separated from radium D by precipitation of the latter with barium sulphate,

Fig. 1.



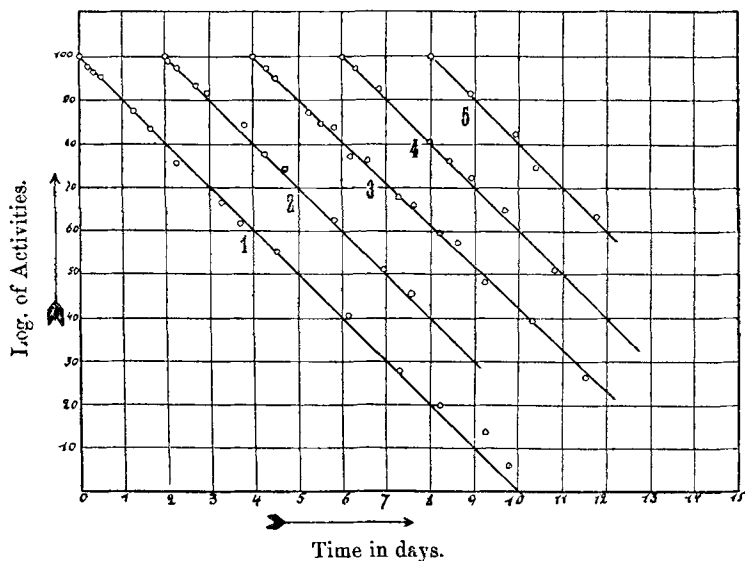
and its activity was found to decay, according to an exponential law, with a period of 5 days. The results obtained are shown in Table II. See also fig. 2, curve 2.

TABLE II.

Time in Days.	Activities in arbitrary units, initial value taken =100.	
	Experimental.	Theoretical for 5 days period.
0	100	100
0.1	98.3	98.6
0.6	91.1	91.7
0.9	88.8	88.2
1.8	78.4	77.9
2.1	74.7	74.8
2.8	70.2	67.8
3.9	58.2	53.3
5.0	49.5	50.0
5.8	45.6	44.6

Another portion of the same preparation was heated in a blowpipe flame until its activity was reduced from 60 divisions per minute to 5 divisions per minute. This was again found to fall to half value in 5 days (see fig. 2, curve 4).

Fig. 2.



Finally, radium D was separated incompletely from another preparation, and was divided into two parts. The β -ray activity of the one was measured until it had reached a final constant value 6.5. Subtracting this value from the readings and plotting on logarithmic paper we get a straight line showing a period of 5 days. The results are given in Table III. (see also fig. 2, curve 1).

The other portion was heated on a platinum crucible lid in a blowpipe flame, in order to get rid of the radium D. The time period of the residue was found to be 5.1–5.2 days; the excess of .1–.2 day over previously found values being probably due to a very small quantity of radium D left behind after heating (see fig. 2, curve 3). Radium E separated from old radium solution gave again the period of 5 days (see fig. 2, curve 5). The variation with time of the β -ray activity of the various preparations is thus consistent with the view that only one product is present between radium D and radium F. The absorption of the rays from

TABLE III.

Time in Days.	Activities in Arbitrary Units.		
	Activities observed.	Activities minus final constant 6.5.	Activities minus constant, reduced to 100.
0	17.6	11.1	100
0.2	17.4	10.9	98.2
0.5	17.1	10.6	95.2
1.1	16.1	9.6	86.5
1.4	15.6	9.1	81.9
1.6	15.4	8.9	80.1
2.2	14.5	8.0	72.0
3.2	13.5	7.0	63.0
3.5	13.2	6.7	60.2
4.5	12.3	5.8	52.4
5.2	11.9	5.4	48.6
6.2	11.2	4.7	42.2
7.2	10.6	4.1	36.8
8.2	10.1	3.6	32.4
9.4	9.7	3.2	28.8
10.6	9.1	2.6	23.4
14.2	7.8	1.3	11.7
32	6.7	0.2	1.8
62	6.5	0	0
122	6.5	0	0

radium E was also investigated. According to Hahn and Meitner* the rays from a single radioactive product are absorbed according to an exponential law. The rays from radium E in radio-lead were examined by Hahn, who found that the absorption curve departed from the exponential long before the γ -ray effect could influence it, since this latter has been found by Meyer and v. Schweidler to be .03 per cent., and by Schmidt .016 per cent. of the total activity. Hahn showed that this deviation was due to some radium emanation remaining in radio-lead, which could be got rid of by heating. Meyer and v. Schweidler found that the β rays from radium E₂ are absorbed approximately according to an exponential law, the coefficient λ for aluminium being 44 cm., and that some soft β rays also come from the long period products, which are half absorbed by 1.5×10^{-4} cm. of aluminium. The absorption of the β rays from radium E was also measured in the present case and found to be exponential, and the absorption coefficient for aluminium found to be 43 cm.⁻¹ and for copper 164 cm.⁻¹

* *Phys. Zeit.* ix. p. 321 (1908).

The Constant of Radium D.

The determination of the constant of transformation of radium D presents some difficulties, as its period is too long for direct measurements. Meyer and v. Schweidler found its period to be about 12 years, by comparing the initial activity of radium C with that due to radium F after a known interval had elapsed. In the present experiments a similar method has been adopted, with the difference that the α particles emitted from radium F have been counted by the scintillation method. This avoids the uncertainty due to the correction for the different ranges of the α particles from radium C and radium F.

A known quantity of emanation was sealed up in a glass tube. The emanation was transformed into radium D, and this in turn gave rise to radium F (polonium). After a definite interval the tube was opened and the number of scintillations per second from the deposit of polonium in the tube was directly counted.

An approximate estimate of the period of radium D can at once be made from such an observation. The initial quantity of emanation in the tube was determined in terms of radium by the γ -ray method. The number n of α particles emitted per second from the emanation is known from the counting experiments of Rutherford and Geiger*. If λ_1 is the constant of the emanation the total number of emanation

atoms present is $\frac{n}{\lambda_1} = N$. Since the time periods of the emanation and its short-lived products are very small compared with that of radium D and radium F, it may be supposed as a first approximation that the emanation changes at once into radium D, and that this changes slowly but directly into radium F. On this assumption the number of atoms of radium D produced is $\frac{n}{\lambda_1}$. The number of atoms of radium F produced per second is $\frac{\lambda_2 n}{\lambda_1}$, where λ_2 is the constant of radium D. Since radium D has a long period of transformation, radium F is initially produced at a nearly constant rate, and the amount of it, S say, present after a time t , is given by

$$S = \frac{\lambda_2 n}{\lambda_1 \lambda_4} (1 - e^{-\lambda_4 t}),$$

where λ_4 is the constant of radium F. The number of atoms

* Proc. Roy. Soc. A. vol. lxxxi. (1908).

of radium F breaking up per second is $\lambda_4 S$, which is equal to

$$\frac{\lambda_2 n}{\lambda_1} (1 - e^{-\lambda_4 t}).$$

The value of $\lambda_4 S$ is deduced experimentally from the counting experiments. Since the values of λ_1 and λ_4 are known, the value of λ_2 , the constant of radium D, can at once be deduced.

In the more complete theory it is necessary to take into account the period of the emanation and of radium E. The emanation may be supposed to be transformed directly into radium D, for the intervening products have short periods of transformation. Let $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, be the constants of transformation of the emanation, radium D, radium E, and radium F respectively. Let N be the number of atoms of emanation present initially, and S the number of atoms of radium F present at time t after the introduction of the emanation. Then

$$S = N (A e^{-\lambda_1 t} + B e^{-\lambda_2 t} + C e^{-\lambda_3 t} + D e^{-\lambda_4 t}).$$

The values of the coefficients A, B, C, D were deduced for me by Mr. H. Bateman, to whom I am very much indebted.

$$A = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)(\lambda_4 - \lambda_1)}$$

$$B = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_1 - \lambda_2)(\lambda_3 - \lambda_2)(\lambda_4 - \lambda_2)}$$

$$C = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)(\lambda_4 - \lambda_3)}$$

$$D = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_1 - \lambda_4)(\lambda_2 - \lambda_4)(\lambda_3 - \lambda_4)}.$$

It can easily be shown that for the time interval in the experiment, $A e^{-\lambda_1 t}$ and $C e^{-\lambda_3 t}$ are very small and can be neglected. In order to obtain the values of B and D it is necessary to know the constant of radium D approximately. This can be done by the approximate theory already mentioned. Writing the expression for B in the form

$$B = \frac{\lambda_2}{\lambda_4} \left(\frac{1}{1 - \frac{\lambda_2}{\lambda_1}} \cdot \frac{1}{1 - \frac{\lambda_2}{\lambda_3}} \cdot \frac{1}{1 - \frac{\lambda_2}{\lambda_4}} \right),$$

and taking

$$\begin{aligned}\lambda_1 &= 2.08 \times 10^{-6} \text{ (sec.}^{-1}\text{)} \text{ as the constant of emanation,} \\ \lambda_2 &= \text{about } 1.19 \times 10^{-9} \quad \text{,,} \quad \text{,,} \quad \text{radium D,} \\ \lambda_3 &= 1.60 \times 10^{-6} \quad \text{,,} \quad \text{,,} \quad \text{radium E,} \\ \lambda_4 &= 5.81 \times 10^{-8} \quad \text{,,} \quad \text{,,} \quad \text{radium F,}\end{aligned}$$

we get $B = 1.02 \frac{\lambda_2}{\lambda_4}$.

Similarly we find $D = 1.09 \frac{\lambda_2}{\lambda_4}$.

Consequently

$$\frac{\lambda_4 S}{N} = \lambda_2 (1.02 e^{-\lambda_2 t} - 1.09 e^{-\lambda_4 t}).$$

Since the time period of radium D (about 16 years) is long compared with the time of observation (less than one year) the value $e^{-\lambda_2 t}$ is very nearly 1. Its value is found with sufficient accuracy by taking the value of λ_2 found by the approximate calculation. Since $\lambda_4 S$ is equal to the total number of α particles expelled from radium F per second, and the values of N and λ_4 are known, the value of λ_2 can at once be deduced.

Experimental Method.

The emanation tubes in which the growth of polonium was observed were of the shapes shown in figs. 3 and 4.

Fig. 3.

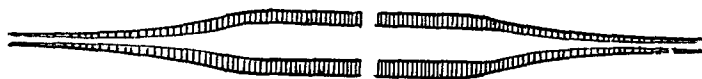


Fig. 4.



These had been used in experiments upon the decay of the radium emanation. The initial amount of emanation had been accurately measured by the γ -ray method. The emanation decayed *in situ* in the tubes, and had practically disappeared before the tubes were examined for their content of polonium. For this purpose the tubes of the shape shown in fig. 3 were cut in two, and the number of α particles

emitted from each part was counted by the scintillation method. In the tube of shape shown in fig. 4 the mica plate was removed. The open tube was fixed centrally in a glass tube (as in fig. 5), at one end of which was placed a

Fig. 5.



B. Zinc-sulphide screen. A. Microscope.

piece of zinc sulphide screen. The tube was so arranged that the α particles from each part of it could fall on the screen. The apparatus was exhausted to a low pressure. The number of scintillations which fell per minute on a definite small area of the screen was counted by a low-power microscope in the usual way. The diameter of the circular area of the screen in the field of the microscope was 1.05 mm. and its area .00866 sq. cm. The part of the screen used for the counting experiment had been previously calibrated by Dr. H. Geiger, who found that the number of scintillations observed was on the average 10 per cent. less than the number of α particles falling upon it. To correct for this, the number of scintillations observed is in all cases increased by 10 per cent. As the emanation tubes were somewhat irregular in shape the following method was adopted in deducing the total number of α particles emitted per second by the polonium in the tube. Suppose the tube to be divided into a number of rings of equal length. As a first approximation, it may be supposed that the amount of polonium on the walls of the ring is proportional to the volume included in the ring. This should evidently be the case, for the deposit from the emanation should be proportional to the amount of emanation initially contained in that part. Since the diameters of the rings are in all cases small compared with the distance from the screen, the polonium may be supposed concentrated at the centre of each ring. Let v_1, v_2, \dots be the volumes of the rings, d_1, d_2, \dots the distances of the middle parts from the screen, then

$$\frac{v}{d^2} = \frac{v_1}{d_1^2} + \frac{v_2}{d_2^2} + \dots,$$

where v is the total volume of the tube, d the mean distance, to be determined on the assumption that all the polonium is concentrated at a point. If $v=1$, then v_1, v_2, \dots are the

respective fractions of the total volume for the rings. If m be the number of α particles per sq. cm. per second falling on the screen, the total number of α particles emitted is $4\pi d^2 m$. A typical experiment is described below. A conical tube of the shape shown in fig. 4 was filled on December 7th, 1908, with an amount of emanation corresponding to the equilibrium quantity from 10.5 mgrm. of radium. This was opened and the scintillations counted on October 23rd, 1909, an interval of 320 days. The distance of the zinc sulphide screen from the end of the tube was 12.4 cm. The number of scintillations observed, with the 10 per cent. correction added, was 31.2 per minute, or 0.54 per second, for an area of screen of .00866 sq. cm. The corresponding number m per second for 1 sq. cm. of the screen is 60.0. The tube used was 10.3 cm. long, and for the purpose of calculation was divided into five parts of equal length. If v_1, v_2, v_3, v_4, v_5 represent the volumes of the parts, we have

$$\begin{array}{ll} v_1 = .474 v & d_1 = 13.3 \text{ cm.} \\ v_2 = .293 v & d_2 = 15.3 \text{ cm.} \\ v_3 = .156 v & d_3 = 17.3 \text{ cm.} \\ v_4 = .066 v & d_4 = 19.3 \text{ cm.} \\ v_5 = .009 v & d_5 = 21.3 \text{ cm.} \end{array}$$

where v is the total volume, and where d_1, d_2, d_3, d_4, d_5 , are the mean distances of the rings.

$$\frac{1}{d^2} = .0462$$

$$d^2 = 216.0.$$

The total number of α particles emitted per second, $S = 4\pi d^2 m = 1.63 \times 10^5$. This is the number of α particles from the polonium, at a time 320 days after the tube was filled.

By means of the approximate theory already considered the constant of change λ_2 of radium D is given by

$$\lambda_2 = \frac{\lambda_4 S \lambda_1}{n(1 - e^{-\lambda_4 t})}.$$

Now $S = 1.63 \times 10^5$, the total number of α particles emitted from the polonium per second; λ_1 for the emanation $= 2.08 \times 10^{-6}$ (sec.⁻¹); $(1 - e^{-\lambda_4 t}) = .7983$, taking the half

period of polonium as 138 days ;

$$n = \frac{10.5}{1000} \times 3.4 \times 10^{10} = 3.57 \times 10^8,$$

since Rutherford* has shown that 3.4×10^{10} atoms of radium and its products break up per second. Substituting these values, $\lambda_2 = 1.19 \times 10^{-9}$ (sec.⁻¹). This gives for the half period of radium D 18.5 years. Using this approximate value of λ_2 the correct value can at once be deduced from the more accurate formula, viz.

$$\frac{\lambda_4 S}{N} = \lambda_2 (1.02 e^{-\lambda_2 t} - 1.09 e^{-\lambda_4 t}).$$

Substituting the approximate value of λ_2 in $e^{-\lambda_2 t}$ we find $1.02 e^{-\lambda_2 t} = .9863$. Remembering that $N = \frac{n}{\lambda_1} = .172 \times 10^{15}$ we get $\lambda_2 = 1.24 \times 10^{-9}$. This corresponds to a period of transformation of 17.7 years.

A number of experiments have been made with different tubes containing different quantities of emanation which had been allowed to stand for different lengths of time. The results are collected in the following table:—

Number of tube.	Amount of radium emanation.	Time before testing in days.	Total number of particles expelled per second.	λ_2 .	Half-transformation period in years.
1	10.5 mgrm.	320	1.63×10^5	1.24×10^{-9}	17.7
2	26.2	119	2.36×10^5	1.33×10^{-9}	16.4
3	25.1	118	2.25×10^5	1.36×10^{-9}	16.1
4	9.4	126	0.867×10^5	1.34×10^{-9}	16.3
5	7.0	129	0.677×10^5	1.37×10^{-9}	15.9

Taking the mean of these determinations we find

$$\lambda_2 = 1.33 \times 10^{-9} \text{ (sec.}^{-1}\text{),}$$

and the half period = 16.5 years, with a probable accuracy of $\pm .5$ years.

* *Loc. cit.*

*Method of Separation of the Long-period Products
from Radium.*

Rutherford* effected a partial separation of radium E from radium D by heating a platinum plate containing a deposit of radium D, radium E, and radium F. Meyer and v. Schweidler† separated the different constituents of radio-lead by means of electrolysis or by depositing on different metals.

Various reagents were used with a view of separating the radioactive products from each other and from radium. It was found that by precipitation with barium sulphate, radium and radium D could be separated from the radium E and polonium in an old solution of radium. The following method was adopted. A certain amount of an old solution of radium was boiled down on a watch-glass to drive off the emanation. The activity of the watch-glass was measured when it had reached a minimum value and found to be 19.5 divs. per minute. This is the measure of the combined activity of radium and polonium left on the glass. Equal portions of the radium solution were taken. Barium salt in varying quantities was added and precipitated as sulphate. The activity remaining in the various portions of the solution was found to be less and less with increasing quantities of barium until a minimum value of 1.5 or 1.4 was reached, after which the larger addition of barium in the remaining portions was found to have no further effect. The experiment was repeated on a larger scale. Where enough barium was added the α -ray activity of the solution measured over some months was found to decay according to an exponential law with a period of about 134 days, which is about the period of polonium. If insufficient barium was added to entrain all the radium the activity of the remaining solution was found to increase in the first few days.

The fact that the quantity of polonium does not diminish with increase of barium salt shows that there is no noticeable entrainment of the polonium by barium sulphate. To test this point more definitely two portions of an acid solution of the active deposit of radium were taken. One portion was evaporated to dryness on a watch-glass, the activity on which was then found to be 21 divs. per minute. In the other portion barium sulphate was precipitated, and, the precipitate having been filtered off, the polonium was likewise evaporated

* Phil. Mag. viii. p. 290 (1905).

† Loc. cit.

to dryness. The activity of this was found to be 19 divs. per minute. In the circumstances of such an experiment this must be regarded as a very satisfactory agreement, especially considering that in the second case the film is always thicker than in the first, thus cutting off a little α -ray activity. In another similar experiment the activities were respectively 4.5 and 4.2 divs. per minute, a loss of about 7.5 per cent.

Similar experiments showed that the β -ray activity was almost completely separated with polonium. These experiments were repeated on a larger scale with different quantities of barium salt. In some cases, when small quantities of barium salt were used, the separation was incomplete (see curve No. 1, fig. 2). When the quantity of barium used was sufficient the β -ray product separated in this way was found to decay exponentially with a period of 5 days. The barium sulphate precipitated was at first inactive, but a β -ray product was found to grow in it having the period of radium E, as shown previously. The barium sulphate was always precipitated in warm dilute solution in presence of hydrochloric acid, and the precipitate was filtered immediately afterwards through a special filter and washed with dilute hydrochloric acid.

Thus radium D can be separated completely from radium E and polonium, and in the case of radium solution, radium and radium D are precipitated and radium E and polonium remain in solution.

Summary.

- (1) Radium E has a period of 5.0 days and follows directly after radium D without any intermediate product.
- (2) The absorption curve for the β rays from radium E is exponential with a coefficient of 43 cm.^{-1}
- (3) The time period of radium D is about 16.5 years.
- (4) Polonium and radium E can be completely separated from radium and radium D.

In conclusion I wish to thank Professor Rutherford for suggesting this research.