THE PERIODS OF TRANSFORMATION OF URANIUM AND THORIUM.

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THE period of uranium has been determined in two ways, first, by counting the scintillations per second from 1 g. of this element and second, by determining the proportion of radium to uranium in minerals, the period of radium being also known. These methods gave 4.8×10^9 and 5.6×10^9 years respectively. A third possibility depends on the linear relation between the logarithms of ranges and decay constants; but this is very inexact as a means of determining periods. In the case of thorium the methods depending on counting the scintillations of the α rays is the only one applicable with any certainty. In the present paper it is shown that the period of a radio-element can be calculated from its range and the ionization current of unit mass. The ranges of all radio-bodies are now known with a fair degree of accuracy; while the ionization currents of uranium and thorium have been carefully measured in connection with other investigations carried out in this laboratory.

It now appears to be well established[1] that the number of ions, N, produced by any α ray of range R is closely proportional to $R^{\frac{3}{2}}$ or $N = aR^{\frac{3}{2}}$. The constant a may be calculated from the work of Geiger and also of Taylor[2] who have determined independently the number of ions formed by an α particle of polonium. The former found 162,000, the latter 164,000. Since $R = 3.58$ cm. for polonium at 0° and 76 cm.,[3]

$$N = 6.97 \times 10^4 R^{\frac{3}{2}}. \tag{1}$$

If I is the total ionization current in amperes of 1 g. of a radioactive element of atomic weight M and decay constant λ, it is easy to show that

$$\lambda \text{ (sec.)} = \frac{IM}{NF} = \frac{IM}{6.97 \times 10^4 R^{\frac{3}{2}} F}, \tag{2}$$

where $F = 96{,}600$ coulombs. If the unit of time is the year

$$\lambda \text{ (year)} = 4.68 \times 10^{-3} \frac{IM}{R^{\frac{3}{2}}}$$

[1] Geiger, Proc. Roy. Soc., A, *82*, 486, 1909. Taylor, Am. Jour. Sci., *28*, 357, 1909, Phil. Mag., *21*, 571, 1911. McCoy and Viol, Phil. Mag. *25*, 333, 1913. McCoy, preceding paper.

[2] Phil. Mag., *23*, 670, 1912.

[3] Geiger, Phil. Mag., *24*, 653, 1912.

and the half-period of decay is

$$T = \frac{\log_e 2}{\lambda} = \frac{148\, R^{\frac{3}{2}}}{IM}. \qquad (3)$$

Since the ionization currents or activities of the equilibrium amounts of the members of a given series are proportional to the two thirds powers of the respective ranges,[1] we may also write

$$T = \frac{148 \Sigma R^{\frac{3}{2}}}{I'M}, \qquad (4)$$

where I' is the ionization current of 1 g. of the mother element, together with the equilibrium amounts of those products the ranges of which are summed.

The periods of uranium and thorium may be calculated by the aid of the formula 4. The two α rays of uranium have ranges of 2.37 cm. and 2.75 cm. at 0° and 76 cm.[2] and 1 g. of uranium gives an α ray ionization current of 4.61×10^{-10} amperes,[3] therefore

$$T = \frac{148 \times 3.741}{4.61 \times 10^{-10} \times 238.5} = 5.04 \times 10^9 \text{ years.}$$

This result may be compared with that obtained by the scintillation method. The number of particles produced per second was found by Geiger and Rutherford[4] to be 2.37×10^4 for 1 g. of U; taking the value of e as known, the period of uranium was found to be 4.8×10^9 years. Closely agreeing results were obtained by counting the scintillations of a uranium mineral. Brown[5] found only about three fourths as many scintillations as Rutherford, his figures indicating a period of 6×10^9 years. Boltwood and Rutherford's determination[6] of the weight of radium in 1 g. of uranium together with Boltwood's[7] value for the period of radium, 2,000 years, lead to a value of 5.6×10^9 years as the period of uranium. Finally by means of the logarithmic law relating ranges and decay constants,[8] the period of uranium is found to be about 7×10^9 years.

It might be thought that equation (3) which gives the period as a

[1] McCoy and Viol, *loc. cit.*

[2] Geiger, Phil. Mag., *24*, 653, 1912.

[3] McCoy and Ashman, Amer. Jour. Sci., *26*, 528, 1908.

[4] Phil. Mag., *20*, 691, 1910.

[5] Proc. Roy. Soc., A, *84*, 151, 1910.

[6] Amer. Jour. Sci., *22*, 1, 1906. Boltwood, *ibid.*, *25*, 296, 1908.

[7] Amer. Jour. Sci., *25*, 493, 1908.

[8] Rutherford, Phil. Mag., *13*, 110, 1907. Geiger and Nuttall, *ibid.*, *22*, 613, 1911; *23*, 438, 1912.

function of the ionization current and the range would be less useful than one obtainable from the law of Geiger connecting ranges and decay constants, which would give the period as a function of the range alone. But the superiority of equation (3) is apparent if we estimate the effect on the calculated period of a small error in R; by equation (3), a decrease of 0.1 per cent. in R decreases the period by less than 0.1 per cent., while by Geiger's law it doubles the calculated period. However, Geiger's law, in addition to its theoretical significance, is very valuable as a means of estimating the periods of such substances as uranium-two and ionium.

The period of thorium may be calculated from data furnished by earlier work done in this laboratory together with a knowledge of the ranges of thorium and its radio-products. The total activities of 1 g. of uranium + U_2 and 1 g. of thorium + all products are 796 and 1,009 respectively, the unit of activity being that of 1 sq. cm. of a thick film of U_3O_8.[1] Since the total ionization current of 1 g. of uranium + U_2 is 4.61×10^{-10} ampere,[2] that of 1 g. of thorium + products is 5.84×10^{-10} ampere. The ranges of the thorium series have recently been redetermined by Geiger and Nuttall,[3] who give the following for 0° and 76 cm. Th, 2.58; Rt, 3.67; ThX, 4.08; Em, 4.74; A, 5.40; C_1, 8.16; C_2, 4.55. For the whole series $\Sigma R^{\frac{2}{3}} = 16.36$, if but 65 per cent. of $R^{\frac{2}{3}}$ for C_1 and 35 per cent. of $R^{\frac{2}{3}}$ for C_2 be taken in the summation,[4] in accord with the fact that C_1 and C_2 give respectively 65 and 35 per cent. as many α particles per second as each of the other members of the series. By means of the above data the calculated period is found to be 1.78×10^{10} years.

A second determination may be made from the activity of thorium alone, which Ashman[5] found to be 11 per cent. of that of thorium + all its products; this result combined with the range of thorium gives a calculated period of 1.86×10^{10} years.

Geiger and Rutherford[6] found that 1 g. of thorium + its products emit 2.7×10^4 α particles per second and calculate therefrom that the period of thorium is 1.31×10^{10} years. Although there is still a wide difference between the latter value and the one here found, which is about 1.8×10^{10} years, yet both are much smaller than the value 3×10^{10} years which had been assumed earlier.[7]

It is obvious that the period of radium might be calculated by formula

[1] McCoy and Ross, Journ. Amer. Chem. Soc., *29*, 1699, 1710, 1907.

[2] McCoy and Ashman, *loc. cit.*

[3] Phil. Mag., *24*, 653, 1912.

[4] Marsden and Barrett, Proc. Phys. Soc., *24*, 50, 1911. Barratt, Le Rod., *9*, 81, 1912.

[5] Ashman, Amer. Journ. Sci., *27*, 65, 1909.

[6] Geiger and Rutherford, Phil. Mag., *20*, 691, 1910.

[7] See Mme. Curie, Die Radioaktivität II., 544.

(3) if the ionization current of unit mass were known with sufficient exactness. Apparently up to the present time this constant has not been determined directly with much accuracy.

SUMMARY.

The period of a radioactive element can be calculated with considerable accuracy from its range and the ionization current of unit weight. The periods so found of uranium and thorium are 5.0×10^9 and 1.8×10^{10} years respectively.

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