THE CONSTANTS OF RADIOACTIVITY.

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IT is now two years since the publication of Kolowrat's table of radioactive constants.[1] The numerous determinations since published require a retabulation of the fundamental values, which is presented herewith, the publication of Le Radium having been suspended because of the war.

In the subjoined table the present system of nomenclature is retained; it is probably still too early to devise a wholly satisfactory one. Since the simplification introduced by Rutherford and Geiger[2] the discovery of branching at the three C members of the disintegration series has again led to confusion. It seems that the term thorium C_2 should be replaced by thorium C', as was done by Soddy,[3] to correspond with radium C' and actinium C', and to indicate the striking analogy between these short-lived beta ray products of the C members. Radium C_2 then remains for the present as the analogue of thorium D and actinium D.

The known radioelements are now thirty-six in number. Varder and Marsden[4] have confirmed the existence of actinium C', previously observed by Marsden and Wilson,[5] and Marsden and Perkins,[6] and indicated by the work of Miss Blanquies.[7] The disintegration series of the three emanations are therefore precisely similar until the D members are reached. Antonoff's discovery[8] of uranium Y has been repeatedly confirmed.[9] It is, however, difficult to assign it to a position in the disin-

[1] Le Radium, *11*, 1 (1914).
[2] Phil. Mag., *22*, 621 (1911).
[3] Chemistry of the Radioelements, Pt. II. Longmans, 1914.
[4] Phil. Mag., *28*, 818 (1914).
[5] Nature, *92*, 29 (1913).
[6] Phil. Mag., *27*, 690 (1914).
[7] Le Radium, *7*, 159 (1910); Comptes Rendus, *151*, 57 (1910).
[8] Phil. Mag., *22*, 419 (1911); *26*, 332, 1058 (1913).
[9] Soddy, Phil. Mag., *27*, 215 (1914). Hahn and Miss Meitner, Physik. Zeitschr., *15* 236 (1914).

tegration series. It is isotopic[10] with uranium X_1 and ionium, and is derived either from uranium 1 or uranium 2 by a subordinate alpha ray change. Both of these origins are anomalous since they demand that one element undergo two different alpha ray disintegrations. Still more a puzzle is the origin of actinium; its solution has not resulted even from the generalization of Fajans,[11] Soddy,[12] and Russell.[13]

The latter is now well established. No exception to it is known. It is used in the chemical classification of the short-lived elements: U X_2, Ra C_2, Act D, Th D, and the three C' members. The chemical properties of the others are taken from the researches of v. Hevesy,[14] v. Hevesy and Paneth,[15] Fleck,[16] McCoy and Viol,[17] Metzener,[18] and Klemensiewicz.[19] The elements of all the three series which are in the same chemical group and on the same side of the emanations in the series are isotopic. That in spite of real differences in atomic weight isotopes are both chemically and spectroscopically indistinguishable is further proved by numerous determinations of the atomic weight of lead of radioactive origin.[20] Hönigschmid and Horowitz[21] have prepared what is probably pure radium G, with an atomic weight of 206.04, as compared with 207.18 for ordinary lead.[22] This points to radium G as the end product of the uranium series and justifies the assumption that the emission of an alpha ray results in the loss of four units in atomic weight. The difference between Hönigschmid's values for radium (225.97) and for radium G is just five times the weight of an atom of helium. Yet the genetic relation between the radioelements and ordinary lead is obscure. Rutherford and

[10] From ισος, equal, and τόπος, place, as suggested by Soddy, in reference to their identical position in the periodic table of the elements. The growing use of the term *isotropic* in this sense is quite indefensible.

[11] Physik. Zeitschr., *14*, 136 (1913); Le Radium, *10*, 61 (1913).

[12] Chem. News, *107*, 97 (1913). Nature, *91*, 571 (1913).

[13] Chem. News, *107*, 49 (1913).

[14] Physik. Zeitschr., *13*, 672 (1912). Phil. Mag., *25*, 390 (1913), *27*, 586 (1914).

[15] Le Radium, *10*, 65 (1913); Monatshefte d. Chemie, *34*, 1393, 1593 (1913), *36*, 795 (1915), Physik. Zeitschr., *15*, 797 (1914), *16*, 45 (1915).

[16] Jour. Chem. Soc., *103*, 381, 1052 (1913).

[17] Phil. Mag., *25*, 333 (1913).

[18] Berichte Chem. Ges., *46*, 979 (1913).

[19] Comptes Rendus, *158*, 1889 (1914).

[20] Richards and Lembert, Jour. Amer. Chem. Soc., *36*, 1329 (1914); Comptes Rendus, *159*, 248 (1914). Maurice Curie, Comptes Rendus, *158*, 1676 (1914). Hönigschmid and Horowitz, ibid., 1796.

[21] Monatshefte d. Chemie, *36*, 355 (1915).

[22] Baxter and Grover, Jour. Amer. Chem. Soc., *37*, 1027 (1915).

Andrade[23] found that the atomic numbers of radium *B* and lead are the same, while recent work by Richards and Wadsworth[24] shows that the atomic volumes of radium *G* and lead are the same. Searching for the end product of thorium, Soddy and Hyman[25] found that lead from thorium minerals showed an abnormally high atomic weight, as if thorium *E* were stable and an isotope of lead. Hönigschmid and Horowitz[21] found no such effect, and Holmes and Lawson[26] could determine no relation between the lead and thorium contents of ancient minerals. Miss Meitner[27] has shown that pure bismuth is not radioactive and is therefore not a beta ray product of lead, as suggested by Fajans and Towara.[28]

New determinations of the ranges of the actinium elements by Meyer, Hess, and Paneth[29] have effected an excellent alignment with Geiger and Nuttall's rule.[30] The graph for the actinium series cuts that for uranium at uranium 2. Radioactinium was found to give two sets of alpha rays, of which the shorter gives exact correspondence with the above rule. McCoy and Leman,[31] however, found a single range of 4.4 cm. The former investigators confirm Hahn and Rothenbach's discovery[32] of alpha rays emitted by actinium itself. The elements which on the present data do not conform with the Geiger-Nuttall rule are actinium *A*, thorium, and ionium. The rule is used for the estimation of the periods of uranium 2, actinium, and the *C'* members.

The values of the transformation constant, λ, the half-life period, *P*, and the range, *R*, which have been changed from Kolowrat's table are based on the work of Soddy and Miss Hitchins[33] for ionium; Meyer, Hess, and Paneth[28] for ionium, polonium and the actinium series; Hahn and Miss Meitner[9] for uranium *Y*; Thaller[34] for radium *D* and *E*; Miss Heimann[35] for thorium; and McCoy and Leman[31] for radioactinium.

[23] Phil. Mag., *27*, 854 (1914).
[24] Jour. Amer. Chem. Soc., *38*, 221 (1916).
[25] Transact. Chem. Soc., *105*, 1402 (1914).
[26] Phil. Mag., *28*, 823 (1914), *29*, 673 (1915).
[27] Physik. Zeitschr., *16*, 4 (1915).
[28] Naturwissenschaften, *2*, 685 (1914).
[29] Sitzber. kais. Akad. Wiss., Wien, Abt. II*a*, *123*, 1459 (1914).
[30] Phil. Mag., *22*, 613 (1911).
[31] PHYS. REV., *4*, 409 (1914).
[32] Physik. Zeitschr. *14*, 409 (1913).
[33] Phil. Mag., *30*, 209 (1915).
[34] Sitzber. kais. Akad. Wiss., Wien, Abt. II*a*, *121*, 1611 (1912); *123*, 157 (1914).
[35] Ibid., 1369.

The absorption coefficients of the gamma rays in aluminium, μ_γ, have required amendment only in the case of radioactinium[36]; those for the beta rays, μ_β, are unchanged.

Substances.	λ (Sec.$^{-1}$)	P	Chem. Group.	Rays.	$R_{15°}$ (Cms.)	μ_β(Al) (Cm.$^{-1}$)	μ_γ(Al) (Cm.$^{-1}$)
Uranium 1	$4.3\cdot10^{-18}$	$5\cdot10^{9}$ yr.	6	α	2.50		
Uranium X_1	$3.3\cdot10^{-7}$	24.6 d.	4	β		510	24; 0.70; 0.140
Uranium X_2	0.01	1.15 min.	5	β		14.4	
Uranium 2	$1.1\cdot10^{-14}$	$2\cdot10^{6}$ yr.?	6	α	2.90		
Uranium Y	$7.5\cdot10^{-6}$	25.5 hrs.	4	β		300	
Ionium	$2.2\cdot10^{-13}$	10^{5} yr.	4	α	3.11		
Radium	$1.26\cdot10^{-11}$	1730 yr.	2	$\alpha\beta$	3.30	200	354; 16; 0.27
Ra Emanation	$2.085\cdot10^{-6}$	3.85 d.	0	α	4.16		
Radium A	$3.85\cdot10^{-3}$	3.0 min.	6	α	4.75		
Radium B	$4.33\cdot10^{-4}$	26.7 min.	4	β		75	230; 40; 0.51
Radium C_1	$5.93\cdot10^{-4}$	19.5 min.	5	$\alpha\beta$		13.5	0.115
Radium C_2	$8.3\cdot10^{-3}$	1.4 min.	3	β			
Radium C′	$7\cdot10^{+5}$	10^{-6} sec.?	6	α	6.94		
Radium D	$1.39\cdot10^{-9}$	15.83 yr.	4	β		130	45; 0.99
Radium E	$1.66\cdot10^{-6}$	4.85 d.	5	β		43.3	like Ra D
Polonium (RaF)	$5.90\cdot10^{-8}$	136 d.	6	$\alpha\beta$?	3.84		585
Thorium	$1.2\cdot10^{-18}$	$1.5\cdot10^{10}$ yr.	4	α	2.72		
Mesothorium 1	$4.0\cdot10^{-9}$	5.5 yr.	2				
Mesothorium 2	$3.1\cdot10^{-5}$	6.2 hr.	3	β		30	26; 0.116
Radiothorium	$1.09\cdot10^{-8}$	2.02 yr.	4	α	3.87		
Thorium X	$2.20\cdot10^{-6}$	3.64 d.	2	α	4.30		
Th Emanation	0.0128	54 sec.	0	α	5.00		
Thorium A	5.0	0.14 sec.	6	α	5.70		
Thorium B	$1.8\cdot10^{-5}$	10.6 hr.	4	β		110	160; 32; 0.36
Thorium C_1	$1.9\cdot10^{-4}$	60 min.	5	$\alpha\beta$	4.80	16.3	0.096
Thorium D	$3.7\cdot10^{-3}$	3.1 min.	3	β			
Thorium C′	$7\cdot10^{+10}$	10^{-11} sec.?	6	α	8.60		
Actinium	$1\cdot10^{-10}$	200 yrs.?	3	α?	3.56		
Radioactinium	$4.25\cdot10^{-7}$	18.88 d.	4	$\alpha\beta$	4.2	170	25; 0.190
[Radioactinium′]?	$3.2\cdot10^{-6}$?	60 hr.?	?	α?	4.61		
Actinium X	$7.6\cdot10^{-7}$	11.4 d.	2	α	4.26		
Act. Emanation	0.18	3.9 sec.	0	α	5.57		
Actinium A	350	0.002 sec.	6	α	6.27		
Actinium B	$3.2\cdot10^{-4}$	36.1 min.	4	β		soft	120; 31; 0.45
Actinium C_1	$5.37\cdot10^{-3}$	2.15 min.	5	$\alpha\beta$?	5.15		
Actinium D	$2.26\cdot10^{-3}$	4.71 min.	3	β		28.5	0.198
Actinium C′	700	0.001 sec.	6	α	6.45		

The following are general relations involving these constants:

$\lambda P = ln2 = 0.69315$.

$\log^P = A + B \log R$, where A and B are constants for each series.

$R_{T_1P_1} = R_{T_2P_2}((T_1P_2)/(T_2P_1))$, where T is the absolute temperature and P is the pressure.

[36] Phil. Mag., *26*, 937 (1913), *27*, 112 (1914).

$V^3 = aR$, where V is the velocity of the alpha ray and a is a constant. For Ra C', $V = 1.922 \times 10^9$ cm. per sec.[37]

$Q = kR^{2/3}$, where Q is the total ionization due to an alpha ray,[31] and k is a constant.

$\nu_\gamma = c\mu_\gamma^{2/5}$, where ν_γ is the frequency of a gamma ray, and c is a constant. For the penetrating gamma rays from Ra B the wave-length is 1.64×10^{-9} cm.[38]

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[37] Phil. Mag., *28*, 552 (1914).
[38] Phil. Mag., *28*, 263 (1914).