The Journal of the
American Chemical Society

VOL. 53 JULY, 1931 No. 7

THE RADIOACTIVE CONSTANTS AS OF 1930. REPORT OF THE INTERNATIONAL RADIUM-STANDARDS COMMISSION[1,2]

By M. Curie, A. Debierne, A. S. Eve, H. Geiger, O. Hahn, S. C. Lind, St. Meyer, E. Rutherford and E. Schweidler

Received June 13, 1931 Published July 8, 1931

Following the reorganization of the International Union of Chemistry and of the International Atomic Weights Commission, the need has arisen for the publication of special Tables of the Radioactive Constants.

This responsibility has been assumed by the International Radium-Standards Commission chosen in Brussels in 1910, which has expressed its willingness to coöperate with the International Union.

Besides the members of the Committee, the following have taken part as experts: J. Chadwick, I. Joliot-Curie, K. W. F. Kohlrausch, A. F. Kovarik, L. W. McKeehan, L. Meitner and H. Schlundt, to whom it is desired to express especial obligations.

The following report will also be published simultaneously in the *Physikalische Zeitschrift*, *Review of Modern Physics*, *Philosophical Magazine* and *Journal Physique et le Radium.*

General Remarks on Symbols and Terms

The symbols are provisionally retained as used in the texts of St. Meyer–E. Schweidler, F. Kohlrausch, and E. Rutherford, J. Chadwick and C. D. Ellis, as well as in the *Physikalische Zeitschrift*, **19**, 30 (1918); *Zeitschrift für Elektrochemie*, **24**, 36 (1918); and *Jahrb. Rad. u. Elektr.*, **19**, 344 (1923).

For the three radioactive gases the use of the terms radon (Rn), thoron (Tn), and actinon (An) is recommended (*Z. anorg. Chem.*, **103**, 79 (1918)), and as general term for elements of atomic number **86** the retention of the word "emanations" (Em) for the three isotopes. The words emanate, emanating power, etc., are retained.

---

[1] To facilitate desirable changes and additions in subsequent years it is requested that data, notes and suggestions be sent to: Prof. Dr. Stefan Meyer, Institut für Radiumforschung, Boltzmanngasse 3, IX Vienna, Austria.

[2] A summary of literature on decay constants and ranges and on absorption coefficients is to be published in other versions of this report, to appear in the July issue of the *Physikalische Zeitschrift* and of the *Review of Modern Physics.*

The designation "radio-lead" is restricted to the natural radioactive mixture of lead isotopes in minerals and is not used to designate RaD.

RaG, ThD and AcD shall be called uranium-lead, thorium-lead and actinium-lead, respectively. The mixture of RaG and AcD will also be designated uranium-lead.

Instead of the designation "Isotopic Weight" (Poids isotopique) as used in the earlier "Tables internationales des éléments radioactifs" for the whole numbered atomic weights or the number of hydrogen nuclei, the word "Proton number" is proposed.

Symbols:

UI, UX_1, UX_2, UII, Io, Ra, Rn, RaA, RaB, RaC′, RaC″, RaD, RaE, RaF=Po, RaG, UY, UZ.
Th, $MsTh_1$, $MsTh_2$, RdTh, ThX, Tn, ThA, ThB, ThC′, ThC″, ThD.
AcU, Pa, Ac, RdAc, AcX, An, AcA, AcB, AcC, AcC′, AcC″, AcD.
Pa is for protactinium (not Proto-actinium).
Em is the joint symbol for Rn, Tn and An.

The following report contains: I, Basic Values; II, Units; III, Constants.

I. Basic Values

(1)	R. T. Birge, *Phys. Rev.*, (2) **33**, 265 (1929), Supplement 1.1–73, July 1929	
(1a)	R. T. Birge, *ibid.*, (2) **35**, 1015 (1930)	
(2)	H. L. Curtis, *Bur. Stand. J. Research*, **3**, 63 (1929)	c = 299790 km./sec.
(3)	Michelson, 1927 (older value 299850)	c = 299796
(4)	Karolus and Mittelstaedt, 1928	c = 299778
(4a)	W. Grotrian, *Naturwiss.*, **17**, 201 (1929)	
(5)	R. A. Millikan, *Science*, **69**, 481 (1929)	$e = 4.770 \cdot 10^{-10}$ E. S. U.
(6)	J. A. Bearden, *Proc. Nat. Acad.*, **15**, 528 (1929)	By Röntgen ray spectroscopy
(7)	A. H. Compton, *Franklin J.*, **208**, 605 (1929)	$e = 4.810 \cdot 10^{-10}$
(8)	E. Bäcklin, *Nature*, **123**, 409 (1929)	4.793
(9)	H. A. Wilson, *Phys. Rev.*, (2) **34**, 1493 (1929)	4.82
(10)	W. N. Bond, *Phil. Mag.*, (7) **10**, 994 (1930)	4.7797
(11)	J. M. Cork, *Phys. Rev.*, (2) **35**, 128 (1930)	4.821
(12)	W. H. Houston, *ibid.*, (2) **30**, 608 (1927)	$c/m_0 = 1.7606 \cdot 10^7$ spectroscopic
(13)	H. D. Babcock, *Astrophys. J.*, **69**, 43 (1929)	$1.7606 \cdot 10^7$ spectroscopic
(14)	F. Kirchner, *Physik. Z.*, 31, 1073 (1930)	1.7602 Deflection of cathode rays
	Ann. Physik, (5) **8**, 975 (1931)	1.7598 ± 0.0025
(15)	C. T. Perry and E. L. Chaffee, *Phys. Rev.*, (2) **36**, 904 (1930)	1.761 Deflection of cathode rays
(16)	A. Upmark, *Z. Physik*, **55**, 569 (1929)	
(17)	A. R. Olpin, *Phys. Rev.*, (2) **36**, 251 (1930)	

Velocity of Light

$c = 2.9980 \cdot 10^{10}$ cm./sec. Literature, (1), (2), (3), (4)

II. Chemical Units

The chemical atomic weights and quantitative relations are based on O = 16.0000. The discovery of the oxygen isotopes O^{18} and O^{17} in the estimated proportions: $O^{16}:O^{17}:O^{18} = 10{,}000:1:8$ requires a sharper definition.

In contrast to the chemical definition, O = 16.0000 for the isotopic mixture, it is proposed for questions of atomic structure and radioactivity in the sense of Aston's measurements to choose $O^{16} = 16.0000$.

For the isotopic mixture in the ratios (very uncertain) given above, O = 16.0017, R. Mecke and W. H. J. Childs (*Z. Physik*, **68**, 362 (1931), estimate O = 16.0035 ± 0.0003).

Corresponding to $O^{16} = 16.0000$, other values are

H = 1.0078 (Aston)	absolute:	$1.662\cdot10^{-24}$ g.
He = 4.00216 (Aston)	absolute:	$6.599_4\cdot10^{-24}$ g.
m_0 of $O^{16}/16.00 = 1.00000$	absolute:	$1.6490\cdot10^{-24}$ g.
m_0 (proton) = 1.0072	absolute:	$1.661\cdot10^{-24}$ g.
m_0 (alpha) = 4.00106	absolute:	$6.598\cdot10^{-24}$ g.
m_0 (electron) = 0.000548 for $e/m_0 = 5.2765\cdot10^{17}$ E. S. U.	absolute:	$9.040\cdot10^{-28}$ g.

Faraday Number

$F = 96489 \pm 5$ abs. coulomb (1)
96494 ± 1 internat. coulomb

Elementary Charge

$e = 4.770\cdot10^{-10}$ E. S. U. (Millikan) (5)
($4.9\cdot10^{-10}$ E. S. U. by x-ray spectroscopy (6), (7), (8), (9), (10), (11)

Specific Charge

$e/m_0 = 1.760\cdot10^7$ abs. magnet. U./g. [spectroscopic (1), electron deflection (14), (15)]
$= 5.276_5\cdot10^{17}$ E. S. U./g.
$1.769\cdot10^7$ abs. mag. U./g.
$= 5.303\cdot10^{17}$ E. S. U./g. Older deflection expts. (1), (4a), (10)

Planck's Constant

$h = 6.547\cdot10^{-27}$ erg. sec. (1)
$= 6.5596\cdot10^{-27}$ erg. sec. (10)
$= 6.591\cdot10^{-27}$ erg. sec. (4a)
$= 6.541\cdot10^{-27}$ erg. sec. (17)

Avogadro's Number

$L = Fc/e = 6.0644\cdot10^{23}$ mol.$^{-1}$ for $e = 4.770\cdot10^{-10}$
$= 6.0265\cdot10^{23}$ mol.$^{-1}$ for $e = 4.80\cdot10^{-10}$
1 Year = 365.24223 days = $3.155693\cdot10^7$ sec.
1 Sec. = $3.168876\cdot10^{-8}$ yr.

Derived Values

$\beta = v/c$ $c^2 = 8.988004\cdot10^{20}$

$$\eta = \frac{1}{\sqrt{1-\beta^2}}$$

$m = m_0\eta$ $2e = 9.540\cdot10^{-10}$
$m_0c^2 = 5.9303\cdot10^{-3}$ for α-particles
$m_0c^2 = 8.1207\cdot10^{-7}$ for $e/m_0 = 5.276_5\cdot10^{17}$ E. S. U./g. for β-particles
$m_0c^2/{}^2e = 6.2162\cdot10^6$ for α-particles
$m_0c^2/e = 1.7034\cdot10^3$ for $e/m_0 = 5.276_5\cdot10^{17}$ E. S. U./g. for β-particles

Kinetic energy $E = m_0 c^2 (\eta - 1)$ for α-particles: $E = 5.9303 \cdot 10^{-3} (\eta - 1)$ erg.
Kinetic energy in volt-electrons for β-particles: $E = 8.1252 \cdot 10^{-7} (\eta - 1)$ erg.
Velocity in equiv. volts $P = 299.80E/2e = 3.1426 \cdot 10^{11}E$ for α-particles
$P = 299.80E/e = 6.2851 \cdot 10^{11}E$ for β-particles

Product of the magnetic field strength and the radius of curvature of the path:

$$\log R = (m_0c^2/2e)\eta\beta = 6.2162 \cdot 10^{6}\,\eta\beta \text{ for } \alpha\text{-particles}$$
$$\log R = (m_0c^2/e)\eta\beta = 1.7034 \cdot 10^{3}\,\eta\beta \text{ for } \beta\text{-particles}$$
$$\lambda = hc/E = 1.9628 \cdot 10^{-16}/E \text{ for } h = 6.547 \cdot 10^{-27}$$
$$\lambda = hc/E = 1.9637 \cdot 10^{-16}/E \text{ for } h = 6.55 \cdot 10^{-27}$$

Z = number of α-particles emitted per second from 1 g. of Ra

Earlier literature to 1926, St. Meyer–E. Schweidler, "Radioaktivität," p. 401.

(1) H. Jedrzejowski, *Compt. rend.*, **184**, 1551 (1927); *Ann. Physik*, **9**, 128 (1928)	$Z = 3.50 \cdot 10^{10}$
(2) I. Curie and F. Joliot, *Compt. rend.*, **187**, 43 (1928)	$3.7 \cdot 10^{10}$
(3) H. J. Braddick and H. M. Cave, *Proc. Roy. Soc.* (London), **121**, 368 (1928); *Nature*, **122**, 789 (1928); also G. Ortner, *Wien. Ber.* **138**, 117 (1929); *Mitt. Ra-Inst.*, Nr. 229	3.69
(4) F. A. Ward, C. E. Wynn-Williams and H. M. Cave, *Proc. Roy. Soc.* (London), **125**, 713 (1929)	3.66
(5) S. H. Watson and M. C. Henderson, *ibid.*, **A118**, 318 (1928) (indirect)	3.72
(6) G. Hoffman, *Physik. Z.*, **28**, 729 (1927); H. Ziegert, *Z. Physik*, **46**, 668 (1928)	3.71
(7) G. Ortner and C. Stetter, *ibid.*, **54**, 475 (1929)	3.72
(8) L. Meitner and W. Orthmann, *ibid.*, **60**, 143 (1930)	3.68
(9) E. Rutherford, J. Chadwick and C. D. Ellis, "Radiations of Radioactive Substances," **1930**, p. 63	3.70

NOTE.—The chief source of error lies in the value for the radium equivalent of the preparation (*e. g.*, of RaC). This arises from the decay curve of RaB–RaC. The standardization is not exact to 0.5 because the standards are not more accurate than this and on account of the different shapes of standard and unknown the comparison involves further inaccuracy. Moreover, in the washing of the preparation with alcohol to remove residual radon, RaB is dissolved in excess of RaC [*Mitt. Ra. Inst.*, No. 254; *Wien Ber.*, **139**, 231 (1930)]. The theoretical curve is thereby disturbed in the first part of the decay of the preparation so that differences of 1% in the value of active deposit result. This error would cause a minimal value of Z. Use of the value **$3.7 \cdot 10^{10}$** is recommended in accord with lit. (9).

Ratio Ra:U in Old Unaltered Minerals

Earlier Literature: St. Meyer–E. Schweidler, "Radioaktivität," **1927**, 398, **pp.** 404–406, Lit. Nr. 7.22.23.

V. Chlopin and M. A. Paswick, *Akad. Leningrad* (1928) (Russian). (In samples from the same location values varying due to chemical changes are found from 2.18 to $4.17 \cdot 10^{-7}$. Compare also Lind and Whittemore, THIS JOURNAL, **36**, 2066 (1914).

The recommended value is Ra/U = $3.4 \cdot 10^{-7}$; U/Ra = $2.94 \cdot 10^{6}$.

Basic Values for the Calculation of the Number of Ion Pairs Produced by One α-Particle

$k = k_0R^{2/3}$ and calculation of velocity from $v^3 = a_0R_0$
All data refer to 0° and 760 mm.
As basis for k_0: $Zk = 8.18\cdot10^{15}$ (Meyer and Schweidler, "Radioaktivität," 1927, p. 189), and $Z = 3.7\cdot10^{10}$
For RaC′: $R_0 = 6.58$ cm. (see table of ranges)
$k = 8.18\cdot10^{15}/3.7\cdot10^{10} = k_0\, 6.58^{2/3}$ $k_0 = 6.296\cdot10^4$
Based on $R_0 = 6.60$ and $Z = 3.72\cdot10^{10}$ $k_0 = 6.253\cdot10^4$
Based on $R_0 = 6.60$ and $Z = 3.70\cdot10^{10}$ $k_0 = 6.283\cdot10^4$
Recommended: $k_0 = 6.3\cdot10^4$

For a_0, different values are obtained according to the choice of RaC′, ThC′ or Po as reference. This may mean that the relation $v^3 = aR$ is not exact and that the definition of the range (Geiger–Henderson) as the intercept of the descending straight line of the Bragg's curve with the abscissa has no theoretical basis.

For RaC′	$R_0 = 6.58$	$v = 1.022\cdot10^9$	$a_0 = 1.0790\cdot10^{27}$	$a_0^{1/3} = 1.026\cdot10^9$
For ThC′	$R_0 = 8.168$	$v = 2.054\cdot10^9$	$a_0 = 1.0609\cdot10^{27}$	$a_0^{1/3} = 1.020\cdot10^9$
For Po	$R_0 = 3.67$	$v = 1.593\cdot10^9$	$a_0 = 1.1015\cdot10^{27}$	$a_0^{1/3} = 1.032\cdot10^9$
		Recommended:	$a_0 = 1.08\cdot10^{27}$	$a_0^{1/3} = 1.026\cdot10^9$

which differ only slightly from the constants in use

For	[3]$R_0 = 6.60$	$v = 1.922\cdot10^9$	$a_0 = 1.0758\cdot10^{27}$	[4]$a_0^{1/3} = 1.0246\cdot10^9$

(Meyer–Schweidler, p. 629)

Radium content is expressed gravimetrically in grams or mg. of elemental radium, regardless of its state of chemical combination. However, it is always desirable to know the total weight and nature of the compound, with reference to Ra concentration.

Radon (Radium Emanation)

1 Curie is the quantity of Rn in equilibrium with 1 g. Ra
1 Curie Rn has the volume 0.66 cu. mm. at 0° and 760 mm.
1 Curie (Rn without decay products) can with complete utilization of the α-particles maintain by its ionization of air a saturation current of $2.75\cdot10^4$ E. S. U. (0.92 milliampere)

Sub-units are millicurie, microcurie, etc. For the Rn content of waters and gases the sub-unit milli-microcurie (10^{-9}) is frequently used.

1 **Eman** = 10^{-10} curie per liter (10^{-13} curie/cc.) is a term used since 1921 for the Rn content of the atmosphere as a *concentration* unit.

1 **Mache Unit** (1 M. E.) is a concentration unit referred to the Rn content of 1 liter of water or gas, etc. It is that quantity of Rn per liter which without decay products and with complete utilization of the α-particles

---

[3] The basic value 6.60 was the mean of the values of G. H. Henderson, *Phil. Mag.*, [6] **42**, 538 (1921), 6.592, and of H. Geiger, *Z. Physik*, **8**, 45 (1921), 6.608. To R_0 the corresponding value at 15° is $R_{15} = 6.963$ cm.

[4] See Rutherford, Chadwick and Ellis, Ref. (9), p. 86.

can maintain by its ionization of a ira saturation current of 10^{-3} E. S. U. 1 M. E. corresponds to $3.64 \cdot 10^{-10}$ curie/liter = 3.64 Eman.

It is recommended to extend the use of the term *curie* to the equilibrium quantity of any decay product of radium. One must then specify the element, as 1 curie Rn, for example. The Commission does not favor its extension to members outside the Ra family.

On the other hand, the unit quantity of any radioactive element may be expressed in terms of the mass equivalent to 1 g. of Ra with respect to the effects of the rays or to the number of atoms decaying per second.

In the latter sense one defines: 1 mg. of Ra equivalent as that quantity of any radioactive element for which the number of atoms decaying per second is the same as that for 1 mg. of Ra ($3.7 \cdot 10^7$ atoms/sec.).

Since, however, the determination of the number of atoms decaying per second can seldom be made directly, the number will much more frequently be obtained indirectly from radiation effects.

Polonium.—"1 Curie Po" = that amount which, equivalent to 1 gram of Ra, emits $3.7 \cdot 10^{10}$ α-particles per sec. "1 Curie Po" = quantity in radioactive equilibrium with 1 gram of Ra, $2.24 \cdot 10^{-4}$ g. Po.

That quantity of Po whose α-radiation directed to one side only is fully utilized to ionize air and which can support a current of 1 E. S. U. corresponds to $1.68 \cdot 10^{-10}$ g. of Po or $0.75 \cdot 10^{-6}$ curie of Po. 1 Curie of polonium would in the utilization of its rays in all directions support a saturation current in air of $2.66 \cdot 10^6$ E. S. U. 1 Microcurie of Po (one sided radiation) = 1.33 E. S. U.

Mesothorium.—"1 mg. MsTh" usually signifies the γ-ray equivalent of 1 mg. of Ra–RaC, compared after absorption by 5 mm. of lead. This definition is for many reasons (dependence on the age of the preparation and on the experimental conditions (see Meyer–Schweidler, **1927**, pp. 496–497)), inexact and open to criticism. All determinations of content of Ra, Rn, MsTh, Po, etc., must be exactly dated, of course.

III. Radioactive Constants[2]

General Remarks

For U_I it is to be noted that the calculation is made on the basis $Z = 3.70 \cdot 10^{10}$ α/sec.; Ra/U = $3.40 \cdot 10^{-7}$; Avogadro No. = $6.064 \cdot 10^{23}$, with no account taken of the branching of the Ac Series. A correction for this would be so dependent on the value of T assumed for AcU that it would have little significance at present. In any case, however, the values given above are for T and τ upper and for λ lower limits.

For UX_1, the lowest value $T = 23.8$ (1) is mentioned as well as the one preferred by the Commission.

In the Table for R, v, k (Range, Velocity, Ion Production) the directly observed values are denoted by +. The calculation of the other values for

v and k was made by using the basic values denoted ++, with the data for k_0 and a_0 given on page 2441.

U_{II} gives according to the ranges of Laurence improbably low values for T (5). Direct determination (50) gives $T = 3.4 \cdot 10^5$ years in good agreement with the range determinations of Hoffman–Ziegert (42). The adoption of $3 \cdot 10^5$ years is recommended.

Rn The two best determinations made recently, W. Bothe, *Z. Physik*, **16**, 226 (1923), $T = 3.825 \pm 0.003$ days, and I. Curie and C. Chamié, *Compt. rend.*, **178**, 1808 (1924); *J. phys.*, [6] **5**, 328 (1924), $T = 3.823 \pm 0.002$ days, agree within the limits of experimental error. During the first day, their differences in Rn decay by the hour are scarcely noticeable in the fourth place.

For $T = 3.823$ days extended tables have been published by C. Chamié, M. Cailliet and G. Fournier [Paris, Gauthier-Villars, 1930].

Radium E

Earlier accepted value	4.85 days	Recommended: $T = 5.0$ days, and $T = 4.9$ days
L. Bastings, *Phil. Mag.*, **48**, 1075 (1924)	4.985 days	
G. Fournier, *Compt. rend.*, **181**, 502 (1925)	4.86 days	
L. F. Curtiss, *Phys. Rev.*, **27**, 672 (1926)	5.07 days	
J. P. McHutchison, *J. Phys. Chem.*, **30**, 925 (1926)	4.87 days	

For RaC′: see Lit. (15), (16), (16a) in *Physik. Z.*, July, 1931.

For ThC′: Mme. Curie has recently calculated from the Geiger–Nuttall Law: λ = about 10^9 sec.$^{-1}$. In view of the great uncertainty attaching to the values for ThC′, O. Hahn and L. Meitner propose to be content with the statement: $T = 10^{-6}$ sec.

AcC″: A. F. Kovarik points out that 150 curves are found to give $T = 4.71$ min., while Albrecht has only 9 curves for $T = 4.76$ min. Both values are given in the table.

URANIUM FAMILY

At. wt. = atomic weight; P. no. = proton number; at. no. = atomic number; yr. = years; d. = days; h. = hours; m. = minutes; s. = seconds; T = half period; τ = average life; λ = decay constant; ( ) indicates earlier values still in use

		T	λ	τ	Literature
Uranium I	UI	$4.4 \cdot 10^9$yr.	$1.6 \cdot 10^{-10}$yr.$^{-1}$	$6.3 \cdot 10^9$yr.	
At. wt.	238.14	$1.4 \cdot 10^{17}$s.	$5.0 \cdot 10^{-18}$s.$^{-1}$	$2.0 \cdot 10^{17}$s.	*Cf* "Remarks" above
At. no.	92				
P. no.	238				
Uranium X_1	UX_1	24.5d.	$2.83 \cdot 10^{-2}$d.$^{-1}$	35.4d.	51
		$2.12 \cdot 10^6$s.	$3.28 \cdot 10^{-7}$s.$^{-1}$	$3.05 \cdot 10^6$s.	
At. no.	90	23.8d.	$2.90 \cdot 10^{-2}$d.$^{-1}$	34.4d.	1
P. no.	234	$2.06 \cdot 10^6$s.	$3.37 \cdot 10^{-7}$s.$^{-1}$	$2.97 \cdot 10^6$s.	
Uranium X_2	UX_2	1.14m.	0.61m.$^{-1}$	1.64m.	(51) (3a)
(Brevium)	91	68.4s.	$1.01 \cdot 10^{-2}$s.$^{-1}$	98.7s.	2, 3
ca. 99.65%	234				
Uranium Z	UZ	6.7h.	0.103h.$^{-1}$	9.7h.	
ca. 0.35%	91	$2.4 \cdot 10^4$s.	$2.87 \cdot 10^{-5}$s.$^{-1}$	$3.5 \cdot 10^4$s.	
	234				
Uranium II	UII	3.10^5yr.	$2.3 \cdot 10^{-6}$yr.$^{-1}$	$4.3 \cdot 10^5$yr.	
	92	$9.4 \cdot 10^{12}$s.	$7.4 \cdot 10^{-14}$s.$^{-1}$	$1.4 \cdot 10^{13}$s.	4, 5
	234				

URANIUM FAMILY (*Concluded*)

		T	λ	τ	Literature
Uranium Y	UY	24.6h.	$2.82\cdot10^{-2}$h.$^{-1}$	35.5h.	
ca 3%	90	1.03d.	0.675d.$^{-1}$	1.48d.	
	231 or 230	$8.88\cdot10^{4}$s.	$7.81\cdot10^{-6}$s.$^{-1}$	$1.28\cdot10^{5}$s.	

IONIUM–RADIUM FAMILY

		T	λ	τ	Literature
Ionium Io		$8.3\cdot10^{4}$yr.	$8.3\cdot10^{-6}$yr.$^{-1}$	$1.2\cdot10^{5}$yr.	
At. no.	90	$2.6\cdot10^{12}$s.	$2.6\cdot10^{-13}$s.$^{-1}$	$3.8\cdot10^{12}$s.	7, 8, 8a
P. no.	230				
Radium Ra		1590yr.	$4.36\cdot10^{-4}$yr.$^{-1}$	2295yr.	
	88	$5.02\cdot10^{10}$s.	$1.38\cdot10^{-11}$s.$^{-1}$	$7.24\cdot10^{10}$s.	9
	226				
Radon Rn		3.825d.	0.1812d.$^{-1}$	5.518d,	
At. no.	86	$3.305\cdot10^{5}$s.	$2.097\cdot10^{-6}$s.$^{-1}$	$4.768\cdot10^{5}$s.	10
P. no.	222	3.823d.	0.1813d.$^{-1}$	5.515d.	*Cf.* **Remarks**
		$3.303\cdot10^{5}$s.	$2.098\cdot10^{-6}$s.$^{-1}$	$4.765\cdot10^{5}$s.	
Radium A RaA		3.05m.	0.227m.$^{-1}$	4.40m.	11
	84	183s.	$3.78\cdot10^{-3}$s.$^{-1}$	264s.	51
	218				
Radium B RaB		26.8m.	$2.59\cdot10^{-2}$m.$^{-1}$	38.7m.	
	82	$1.61\cdot10^{3}$s.	$4.31\cdot10^{-4}$s.$^{-1}$	$2.32\cdot10^{3}$s.	
	214				
Radium C RaC		19.7m.	$3.51\cdot10^{-2}$m.$^{-1}$	28.5m.	
	83	$1.18\cdot10^{3}$s.	$5.86\cdot10^{-4}$s.$^{-1}$	$1.71\cdot10^{3}$s.	12
	214				
Radium C′ RaC′		*ca.* 10^{-6}s.	10^{6}s.$^{-1}$	10^{-6}s.	13, 14
99.96%	84				15, 16
(99.97%)	214				16a
Radium C″ RaC″		1.32m.	0.525m.$^{-1}$	1.9m.	
0.04%	81	79.2s.	$8.7\cdot10^{-3}$s.$^{-1}$	115s.	17
(0.03%)	210				
Radium D RaD		22yr.	0.0315yr.$^{-1}$	31.7yr.	
	82	$6.94\cdot10^{6}$s.	$1.00\cdot10^{-9}$s.$^{-1}$	$1.00\cdot10^{9}$s.	18, 19, 20
	210				
Radium E RaE		4.9d.	0.141d.$^{-1}$	7.07d.	
	83 or	$4.26\cdot10^{5}$s.	$1.63\cdot10^{-6}$s.$^{-1}$	$6.13\cdot10^{5}$s.	21
	210	5.0d.	0.139d.$^{-1}$	7.2d.	
		$4.32\cdot10^{5}$s.	$1.61.10^{-6}$s.$^{-1}$	$6.22\cdot10^{5}$s.	
Radium F RaF(Po)		140d.	$4.95\cdot10^{-3}$d.$^{-1}$	202d.	22, 23
Polonium	84	$1.21\cdot10^{7}$s.	$5.73\cdot10^{-8}$s.$^{-1}$	$1.75\cdot10^{7}$s.	
	210				
Radium G RaG					
Uranium lead	206.016				
	82				
	206				

ACTINIUM FAMILY

		T	λ	τ	Literature
Actinium Uranium					
AcU		*ca.* 10^{8} to 10^{9}yr.			24
Uranium Y, see Uranium Family					
Protactinium Pa		$3.2\cdot10^{4}$yr.	$2.17\cdot10^{-5}$yr.$^{-1}$	$4.6\cdot10^{4}$yr.	24a, 24b, 25
	91	$1.01\cdot10^{12}$s.	$6.86\cdot10^{-13}$s.$^{-1}$	$1.46\cdot10^{12}$s.	
	231				
Actinium Ac	89	13.5yr.	$5.15\cdot10^{-2}$yr.$^{-1}$	19.4yr.	26
		$4.23\cdot10^{8}$s.	$1.63\cdot10^{-9}$s.$^{-1}$	$6.12.10^{8}$s.	
	227	20 yr.	$3.4\cdot10^{-2}$yr.$^{-1}$	29 yr.	
		$6.3\cdot10^{8}$s.	$1.1\cdot10^{-9}$s.$^{-1}$	$9.2\cdot10^{8}$s.	
Radioactinium RdAc		18.9d.	$3.66\cdot10^{-2}$d.$^{-1}$	27.3d.	27, 28
	90	$1.63\cdot10^{6}$s.	$4.24\cdot10^{-7}$s.$^{-1}$	$2.36\cdot10^{6}$s.	
	227				
Actinium X AcX		11.2d.	$6.17\cdot10^{-2}$d.$^{-1}$	16.2d.	27, 51
	88	$9.7\cdot10^{5}$s.	$7.14\cdot10^{-7}$s.$^{-1}$	$1.40\cdot10^{6}$s.)	
	223 or	11.4d.	$6.08\cdot10^{-2}$d.$^{-1}$	16.4d.	
		$9.85\cdot10^{5}$s.	$7.06\cdot10^{-7}$s.$^{-1}$	$1.42\cdot10^{4}$s.	
Actinon An		3.92s.	0.177s.$^{-1}$	5.66s.	29, 51
	86				
	219				
Actinium A AcA		2.10^{-3}s.	347s.$^{-1}$	$2.88\cdot10^{-3}$s.	30
	84				
	215				
Actinium B AcB		36.0m.	$1.93\cdot10^{-2}$m.$^{-1}$	51.9m.	31
	82	$2.16\cdot10^{3}$s.	$3.21\cdot10^{-4}$s.$^{-1}$	$3.12\cdot10^{3}$s.	
	211				
Actinium C AcC		2.16m.	0.321m.$^{-1}$	3.12m.	27
	83	130s.	$5.35\cdot10^{-3}$s.$^{-1}$	187s.	
	211				
Actinium C′ AcC′		*ca.* 5.10^{-3}s.	*ca.* 140s.$^{-1}$	*ca.* 7.10^{-3}s.	
	84				
0.32%	211				
Actinium C″ AcC″		4.76m.	0.145m.$^{-1}$	6.87m.	32
99.68%	81	286s.	$2.43\cdot10^{-3}$s.$^{-1}$	412s.	
	207 or	4.71m.	0.146m.$^{-1}$	6.83m.	
		283s.	$2.44\cdot10^{-3}$s.$^{-1}$	410s.	
Actinium D					
AcD	207.016(?)				
Actinium lead	82				
Pb^{207}	207				

THORIUM FAMILY

		T	λ	τ	Literature
Thorium Th		$1.8\cdot10^{10}$yr.	$4.0\cdot10^{-11}$yr.$^{-1}$	$2.5\cdot10^{10}$yr.	33
At. wt.	232.12	$5.6\cdot10^{17}$s.	$1.2\cdot10^{-18}$s.$^{-1}$	$8.0\cdot10^{17}$s.	
At. no.	90				
P. no.	232				

THORIUM FAMILY (*Concluded*)

			T	λ	τ	Literature
Mesothorium 1 MsTh$_1$			6.7yr.	0.103yr.$^{-1}$	9.7yr.	
	88		$2.1\cdot10^8$s.	$3.26\cdot10^{-9}$s.$^{-1}$	$3.05\cdot10^8$s.	
	228					
Mesothorium 2 MsTh$_2$			6.13h.	0.113h.$^{-1}$	8.84h.	34
	89		$2.21\cdot10^4$s.	$3.14\cdot10^{-5}$s.$^{-1}$	$3.18\cdot10^4$s.	
	228					
Radiothorium RdTh			1.90yr.	0.365yr.$^{-1}$	2.74yr.	35
	90		$6.0\cdot10^7$s.	$1.16\cdot10^{-8}$s.$^{-1}$	$8.65\cdot10^7$s.	
	228					
Thorium X ThX			3.64d.	0.190d.$^{-1}$	5.25d.	
	88		$3.14\cdot10^5$s.	$2.20\cdot10^{-6}$s.$^{-1}$	$4.54\cdot10^5$s.	
	224					
Thoron Tn			54.5s.	$1.27\cdot10^{-2}$s.$^{-1}$	78.7s.	36
	86					
	220					
Thorium A ThA			0.14s.	4.95s.$^{-1}$	0.20s.	37
	84					
	216					
Thorium B ThB			10.6h.	$6.54\cdot10^{-2}$h.$^{-1}$	15.3h.	
	82		$3.82\cdot10^4$s.	$1.82\cdot10^{-5}$s.$^{-1}$	$5.51\cdot10^4$s.	
	212					
Thorium C ThC			60.5m.	$1.15\cdot10^{-2}$m.$^{-1}$	87.3m.	38
	83		$3.63\cdot10^3$s.	$1.91\cdot10^{-4}$s.$^{-1}$	$5.24\cdot10^3$s.	
	212					
Thorium C′ ThC′			10^{-9}s.	10^9s.$^{-1}$?	10^{-9}s.??	
65%	84	or	$<10^{-6}$	$>10^6$s.$^{-1}$	$<10^{-6}$s.	
65.7%	212					40
Thorium C″ ThC″			3.1m.	$2.24\cdot10^{-1}$m.$^{-1}$	4.47m.	39
35%	81		186s.	$3.73\cdot10^{-3}$s.$^{-1}$	286.3s.	
34.3%	208					40
Thorium D ThD						
	208.016(?)					
Thorium lead	82					
Pb^{208}	208					

QUANTITIES IN RADIOACTIVE EQUILIBRIUM

			M in mass units	
		T	For Ra = 1	For UI = 1
	UI	$1.39\cdot10^{17}$s.	$2.94\cdot10^6$	1.00
	UX$_1$	$2.12\cdot10^6$	$4.4\cdot10^{-5}$	$1.5\cdot10^{-11}$
		$(2.06)\cdot10^6$	$(4.3)\cdot10^{-5}$	
99.65%	UX$_2$	68.4	$1.4\cdot10^{-9}$	$5\cdot10^{-16}$
0.35%	UZ	$2.4\cdot10^4$	$1.7\cdot10^{-8}$	$6\cdot10^{-16}$
	UII	$9.4\cdot10^{12}$	$2.0\cdot10^2$	$6.7\cdot10^{-5}$
3%	UY	$8.88\cdot10^4$	$5.6\cdot10^{-8}$	$1.9\cdot10^{-14}$
97%	Io	$2.6\cdot10^{12}$s.	52.7	
	Ra	$5.02\cdot10^{10}$	1.00	
	Rn	$3.303\cdot10^5$	$6.47\cdot10^{-6}$	

Quantities in Radioactive Equilibrium (*Concluded*)

		T	M in mass units For Ra = 1	For UI = 1
	RaA	183	$3.52\cdot10^{-9}$	
	RaB	$1.61\cdot10^{3}$	$3.04\cdot10^{-8}$	
	RaC	$1.18\cdot10$	$2.23\cdot10^{-8}$	
99.96%	RaC′	*ca.* 10^{-6}	*ca.* $2\cdot10^{-19}$	
0.04%	RaC′′	79.2	$6\cdot10^{-13}$	
	RaD	$6.94\cdot10^{8}$	$1.28\cdot10^{-2}$	
	RaE	$4.26\cdot10^{5}$ (4.9d.)	$7.9\cdot10^{-6}$	
		$4.32\cdot10^{5}$ (5.0d.)	$8.0\cdot10^{-6}$	
Po =	RaF	$1.21\cdot10^{7}$	$2.24\cdot10^{-4}$	
	M for Ra = 1 and 3% Branching Fraction			
	Pa	$1.01\cdot10^{12}$s.	0.62	
	Ac	$4.23\cdot10^{8}$	$2.5\cdot10^{-4}$	
		($6.3\cdot10^{8}$, 20yr.)	($3.7\cdot10^{-4}$)	
	RdAc	$1.63\cdot10^{6}$	$9.8\cdot10^{-7}$	
	AcX	$9.7\cdot10^{5}$	$5.8\cdot10^{-7}$	
	An	3.92	$2.27\cdot10^{-12}$	
	AcA	$2\cdot10^{-3}$	$1.14\cdot10^{-15}$	
	AcB	$2.16\cdot10^{-3}$	$1.21\cdot10^{-9}$	
	AcC	130	$7.2\cdot10^{-11}$	
0.32%	AcC′	*ca.* 10^{-3}	*ca.* $2\cdot10^{-18}$	
99.68%	AcC′′	286	$1.57\cdot10^{-10}$	
		(283)	$1.55\cdot10^{-10}$	

Quantities in Radioactive Equilibrium

		T	M in mass units For Th = 1	For MsTh$_1$ = 1
	Th	$5.6\cdot10^{17}$s.	1.00	$2.7\cdot10^{9}$
	MsTh$_1$	$2.1\cdot10^{8}$	$3.68\cdot10^{-10}$	1.00
	MsTh$_2$	$2.21\cdot10^{4}$	$3.88\cdot10^{-14}$	$1.05\cdot10^{-4}$
	RdTh	$6.0\cdot10^{7}$	$1.05\cdot10^{-10}$	0.286
	ThX	$3.14\cdot10^{5}$	$5.41\cdot10^{-13}$	$1.47\cdot10^{-3}$
	Tn	54.5	$9.23\cdot10^{-17}$	$2.50\cdot10^{-7}$
	ThA	0.14	$2.32\cdot10^{-19}$	$6.31\cdot10^{-10}$
	ThB	$3.82\cdot10^{4}$	$6.23\cdot10^{-14}$	$1.69\cdot10^{-4}$
	ThC	$3.63\cdot10^{3}$	$5.92\cdot10^{-15}$	$1.61\cdot10^{-5}$
65%	ThC′	*ca.* 10^{-9}	*ca.* 10^{-27}	*ca.* $3\cdot10^{-18}$
	or	10^{-6}	10^{-14}	$3\cdot10^{-15}$
35%	ThC′′	186	$1.04\cdot10^{-16}$	$2.83\cdot10^{-7}$

Remarks on "Range" and "Ion Production."—Comparison of the results of different investigations shows that the ranges are not defined with sufficient sharpness to justify the use of three decimal places. Limitation to two places is therefore proposed.

In general, the values of H. Geiger [*Z. Physik*, **8**, 45 (1921)] supplemented by those of G. H. Henderson [*Phil. Mag.*, [16] **42**, 538 (1921)] and the later values (Lit. 41) are the ones used in the following. For U$_{II}$ see the note on page 2443. For RaC′ Mmes. M. Curie and I. Joliot-Curie have made the following summary

	R_{15}	Recommended
H. Geiger, *Z. Physik*, **8**, 45 (1921)	6.971	
G. H. Henderson, *Phil. Mag.*, **42**, 538 (1921)	6.953	6.95 or
I. Curie and F. Běhounek, *J. Phys. Rad.*, **7**, 125 (1926)	6.96	6.96
G. I. Harper and E. Salaman, *Proc. Roy. Soc.* (London), **127**, 175 (1930)	6.94	

Since the basic value for RaC′ which has been used up to the present (*cf.* page 2441) is the mean of the values of Geiger and of Henderson, $R_0 = 6.600$ or $R_{15} = 6.963$, it appears advisable to retain it and to round off R_{15} as 6.96.

There is no agreement yet on the range of α-particles of ThC. Both values $R_{15} = 4.78$ and 4.72 are, therefore, reported.

For the discussion of ranges refer especially to the measurements of S. Rosenblum, *Compt. rend.*, **190**, 1124 (1930), and the sections in Rutherford, Chadwick and Ellis (51), page 82, *et seq.*, and the table on page 86. If one is content with two decimal places for the velocity, then the relation $v^3 = aR$ gives sufficient accuracy for the normal ranges.

The basic value for ion production by α-particles is that for RaC′: $k = 2.2 \cdot 10^5$ (*cf.* page 2441).

For the velocity of α-particles from ThC Rutherford, Chadwick and Ellis (51) choose $1.701 \cdot 10^9$ cm./sec., while Mmes. M. Curie and I. Joliot-Curie propose $1.698 \cdot 10^9$ cm./sec.

Ranges at 0° and 760 Mm. in Air (R_1); at 15° (R_{15})
Velocity (v) and ion production (k)

	R_0	R_{15}	v	k	Literature
UI	2.53	2.67	$1.40 \cdot 10^9$	$1.16 \cdot 10^5$	M.–Schw. (42)
	2.59	2.73	1.41	(1.18)	41, 51
UII	2.96	3.12	1.47	1.29^+	42
	3.11	3.28	1.50	(1.33)	41, 43, 51
Io	3.03	3.19	1.48	1.31	M.–Schw. 41
Ra	3.21	3.39	1.51	1.36^+	42
Rn	3.91	4.12	1.61	1.55	M.–Schw.
RaA	4.48	4.72	1.69	1.70	
RaC	3.9	4.1	1.61	1.55	48a
RaC′	6.600^{++}	6.96	1.922^{++}	2.20^{++}	M.–Schw.
	(6.58)	(6.94)			44, 48
Po	3.67	3.87	1.593^+(1.58)	1.49	45
	(3.72)	(3.92)	(1.59)	(1.50)	44, 46
Pa	3.48	3.67	1.55	1.44	M.–Schw.
RdAc	(4.43)	4.68	1.68	(1.69)	52
and	(4.77) and	4.34	1.64	(1.67)	
AcX	4.14	4.37	1.65	1.61	
An	5.49	5.79	1.81	1.95	
AcA	6.24	6.58	1.89	2.12	
AcC	(5.22)	(5.51)	(1.78)	(1.88)	48a
and →	(4.82) and →	(5.09)	(1.73)	(1.79)	
AcC′	(?6.2?)	(?6.5?)	(1.9?)	*ca.* 2	

Absorption Coefficients for β- and γ-Rays.—Beta and gamma rays are at present best characterized by their spectra. An extensive reproduction of such spectra would exceed the limits of these first tables issued by the Radium-Standards Commission.

The following summaries are cited

L. Meitner, "Handbuch der Physik," by H. Geiger and K. Scheel, Bd. XXII, 1926; St. Meyer and E. Schweidler, "Radioaktivität," Teubner, 1927; K. W. F. Kohlrausch, "Radioaktivität," Bd. XV, Handb. d. Experimentalphysik, W. Wien and F. Harms, 1928; A. F. Kovarik and L. M. McKeehan, "Radioactivity," Bull. of the National Research Council, Nr. 51, Washington, 1929; I. Joliot-Curie, "Données numériques de Radioactivité, Tables annuelles de constantes et donneés numériques," Paris, 1930; E. Rutherford, J. Chadwick and C. D. Ellis, "Radiations from Radioactive Substances," Cambridge, England, 1930.

The absorption coefficients (μ) are in the expression $I = I_0e^{-\mu x}$, somewhat deficiently defined, but for practical measurements and for radioactive identification they constitute very useful data and are therefore given in the following table, as well as the velocity limits for β-rays. μ/ρ is the mass absorption coefficient (ρ = density); D = thickness for half absorption, $0.69315/\mu$. All data refer to aluminum as absorbing material.

BETA RAYS

Substance	Type of decay	μ in cm.$^{-1}$ Al	μ/ρ	D in cm. Al	Literature	Magnetic spectrum, velocity limits in 10^{10} cm./sec.	Remarks[a]	Accompanying γ-rays
UX_1	β	460	170	0.0015	9	1.44–1.74	3L.[b] 1 Bd.	No nuclear γ-rays
UX_2	β	18	6.75	0.038	9	2.46–2.88	2 Bd.	Weak nuclear γ-rays
UZ	β	270 to 36	100 to 13.5	0.0026 –0.019	11	?	?	?
Ra	α	312	116	0.00222	4	1.56–2.04	3 L.	1 Nuclear γ-line
RaB	β	890: 80: 13	330: 29.5: 4.84	0.00078: 0.0087: 0.053	1	1.08–2.47	31 L.	9 Nuclear γ-lines
RaC + C″	$\alpha + \beta$	50: 13	18.5: 4.84	0.0139: 0.053	1	1.14–2.96	63 L.	11 Nuclear γ-lines
RaD	β	5500	2037	0.000126	8	0.96–1.20	5 L.	1 Nuclear γ-line
RaE	β	45.5	16.9	0.0152	13	2.05–2.84	1 Bd.	Weak nuclear γ-ray
UY	β	*ca.* 300	110	0.0023	10	?	?	?
Pa	α	126	47	0.0055	14, 16	1.47–2.35	12 L.	3 Nuclear γ-lines
Ac	β	?	?	?	?	?	?	?
RdAc	α	175	65	0.004	14	0.66–2.3	49 L.	10 γ-lines
AcX	α	?	?	?		0.88–2.22	21 L.	5 γ-lines
AcB	β	*ca.* 1000	370	0.0007	2	1.49	1 L. ?	
AcC AcC″	$\alpha + \beta$ β	29	10.7	0.024	5	2.25–2.56	8 L.	3 Nuclear γ-lines
$MsTh_1$	β	?	?	?		?	?	?
$MsTh_2$	β	40: 20	14.8: 7.4	0.018 –0.034	3	1.09–2.90	31 L.	8 γ-Lines
RdTh	α	420	150	0.0017	6	1.19–1.53	6 L.	2 γ-Lines

BETA RAYS (*Concluded*)

Substance	Type of decay	μ in cm.$^{-1}$ Al	μ/ρ	D in cm. Al	Literature	Magnetic spectrum, velocity limits in 10^{10} cm./sec.	Remarks	Accompanying γ-rays
ThB	β	153	57	0.0045	5.7	1.88–2.99	5 L.	2 Nuclear γ-lines
ThC	$\alpha + \beta$	14.4	5.35	0.048	7			
ThC″	β	21.6	8.0	0.032	7	0.91–2.87	37 L.	11 Nuclear γ-lines
K	β	74: 49	27.4: 18	0.0094 :0.014	 15			 Weak γ-rays
Rb	β	700: 190: 900	260: 70 333	0.001 :0.0037 0.0077	15, 19 12			

GAMMA RAYS

μ_{Al} is arranged to show the assumed origin of the radiation

Substance	Type of decay	M-series	L-series	K-series	Nucleus		Number of lines
UX_1	β	..	24	0.7	..	...	1
UX_2	β	..	..	..	..	0.14	..
Ionium	α	1088	22.7	0.41	..	...	..
Radium	α	354	16.3	..	0.27	...	1
RaB	β	230	40	0.57	..	...	10
RaC + C′	$\alpha + \beta$	..	..	1.49	0.23	0.127	11
RaD	β	..	45	1.17	..	...	1 (Lit. 22)
RaE	β	..	..	..	0.24	...	..
RaF	α	2700	46	..	Like RaC		(Lit. 20, 21)
Pa	α	..	..	..	..	...	3[a] (Lit. 16)
RdAc	α	..	25	..	..	0.19	10
AcX	α	..	..	..	..	...	5
AcB	β	120	31	0.45	..	...	..
AcC″	β	..	..	..	..	0.198	3
$MsTh_2$	β	..	26	..	..	0.116	8
ThX	α	..	..	..	..	...	2 (Lit. 17)
ThB	β	160	32	0.36	..	...	3
ThC″	β	..	..	..	..	0.096	11
K	β	From F = 0.19 From P = 0.59				0.065 0.14	(Lit. 18) (Lit. 19)

[a] Bands (UX_1 to ThC″) have their origin in the primary (nuclear) β-rays; lines in the photo-electrons of the γ-rays.

[b] L, line; Bd., band.