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THE RADIOACTIVE CONSTANTS AS OF 1930

Report of the International Radium-Standards Commission

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

I. Introduction

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 cooperate with the International Union.

Besides the members, M. Curie, A. Debierne, A. S. Eve, H. Geiger, O. Hahn, S. C. Lind, St. Meyer, E. Rutherford, E. Schweidler, 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 be simultaneously published* also in the Physikalische Zeitschrift, in the Journal of the American Chemical Society, Philosophical Magazine, and Journal de Physique et le Radium.

II. General Remarks on Symbols and Terms

The symbols are provisionally retained as used in the texts of St. Meyer and E. Schweidler, F. Kohlrausch and E. Rutherford, J. Chadwick and C. D Ellis as well as in the Phys. Zeits. **19,** 30 (1918), Zeits. f. Elektrochemie **24,** 36 (1918), Jahrb. d. 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 (Zeits. f. 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.

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

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

Instead of the designation "isotopic weight" (*poids isotopique*) as used in the earlier *Tables internationales des éleménts radioactifs* for the whole-numbered atomic weights or the number of hydrogen nuclei, the term "proton number" is proposed.

* 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

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

III. Basic Values

Velocity of light.

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

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: $O^{16}:O^{17}:O^{18} = 10{,}000:1:8$ makes necessary a sharper definition of atomic weights.

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, Zeits. f. Physik **68,** 362, 1931, estimate $O = 16.0035 \pm 0.0003$).

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

H = 1.0078 (Aston)	absolute:	$1.662 \cdot 10^{-24}$g
He = 4.00216 (Aston)		$6.599_4 \cdot 10^{-24}$g
m_0 of $O^{16}/16.00 = 1.00000$		$1.6490 \cdot 10^{-24}$g
m_0 (proton) = 1.0072		$1.661 \cdot 10^{-24}$g
m_0 (alpha) = 4.00106		$6.598 \cdot 10^{-24}$g
m_0 (electron) = 0.000548		$9.040 \cdot 10^{-28}$g

(for $e/m_0 = 5.2765 \cdot 10^{17}$e.s.u./g)

Faraday number.

$F = 96489 \pm 5$ abs. coulomb Reference 1
$= 96494 \pm 1$ internat. coulomb

Elementary charge.

$e = 4.770 \cdot 10^{-10}$e.s.u.(Millikan) Reference 5
$4.9 \cdot 10^{-10}$ e.s.u. by x-ray spectroscopy. References 6, 7, 8, 9, 10, 11

Specific charge.

$e/m_0 = 1.760 \cdot 10^7$ abs. e.m.u./g	Spectroscopic, reference 1; electron deflection, references 14, 15.
$= 5.2765 \cdot 10^{17}$ e.s.u./g	
$= 1.769 \cdot 10^7$ abs. e.m.u./g	Older electron deflection experiments, references 1, 4a, 10
$= 5.303 \cdot 10^{17}$ e.s.u./g	

Planck's constant.

$h = 6.547 \cdot 10^{-27}$ erg · sec.	Reference 1
$= 6.5596$	Reference 10
$= 6.591$	Reference 4a
$= 6.541$	Reference 17

Avogadro's number.

$L = Fc/e = 6.0644 \cdot 10^{23}$ mole^{-1}	for $e = 4.770 \cdot 10^{-10}$ e.s.u.
$= 6.0265$	for $e = 4.80$

Year.

1 year $= 365.24223$ day $= 3.155693 \cdot 10^{7}$ sec.
1 sec. $= 3.168876 \cdot 10^{-8}$ year

Derived constants.

$\beta = v/c$, $\eta = (1-\beta^2)^{-1/2}$, $m = m_0\eta$
$c^2 = 8.988004 \cdot 10^{20}$ cm^2/sec^2
$2e = 9.540 \cdot 10^{-10}$ e.s.u.
$m_0c^2 = 5.9303 \cdot 10^{-3}$ for alpha-particles
$m_0c^2 = 8.1207 \cdot 10^{-7}$ for $e/m_0 = 5.276_5 \cdot 10^{17}$ e.s.u./g for beta-particles
$m_0c^2/2e = 6.2162 \cdot 10^{6}$ for alpha-particles
$m_0c^2/e = 1.7034 \cdot 10^{3}$ for $e/m_0 = 5.276_5 \cdot 10^{17}$ e.s.u./g for beta-particles

Kinetic energy

$E = m_0c^2(\eta - 1) = 5.9303 \cdot 10^{-3}(\eta - 1)$ erg for alpha-particles
$= 8.1252 \cdot 10^{-7}(\eta - 1)$ erg for beta-particles

Velocity in equivalent volts

$p = 299.80E/2e = 3.1426 \cdot 10^{11}E$ for alpha-particles
$= 299.80E/e = 6.2851 \cdot 10^{11}E$ for beta-particles

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

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

Literature.

1. R. T. Birge, Phys. Rev. (2) **33,** 265 (1929); Phys. Rev. Supp. **1,** 1–73 (1929)

1a. R. T. Birge, Phys. Rev. (2) **35,** 1015 (1930)

2. H. L. Curtis, Bur. Stds. J. Research **3,** 63 (1929) — $c = 299790$ km/sec.

3. Michelson, 1927, (older value 299850) — $c = 299796$ km/sec.

4. Karolus and Mittelstaedt, 1928 — $c = 299778$ km/sec.

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. (June, 1929) — By x-ray spectroscopy

7. A. H. Compton, J. Franklin Inst. **208,** 605 (1929) — $e = 4.810 \cdot 10^{-10}$e.s.u.

8. E. Bäcklin, Nature **123,** 409 (1929) $e=4.793\cdot 10^{-10}$e.s.u.
9. H. A. Wilson, Phys. Rev. (2) **34,** 1493 (1929) $e=4.82\cdot 10^{-10}$e.s.u.
10. W. N. Bond, Phil. Mag. (7) **10,** 994 (1930) $e=4.7797\cdot 10^{-10}$e.s.u.
11. J. M. Cork, Phys. Rev. (2) **35,** 128 (1930) $e=4.821\cdot 10^{-10}$e.s.u.
12. W. H. Houston, Phys. Rev. (2) **30,** 608 (1927), spectroscopic $e/m_0=1.7606\cdot 10^7$e.m.u./g
13. H. D. Babcock, Astrophys. J. **69,** 43 (1929), spectroscopic $e/m_0=1.7606\cdot 10^7$e.m.u./g
14. F. Kirschner, Phys. Zeits. **31,** 1073 (1930), cathode rays $e/m_0=1.7602\cdot 10^7$e.m.u./g
    Ann. d. Physik (5) **8,** 975 (1931), cathode rays $e/m_0=1.7598\cdot 10^7$e.m.u./g
15. C. T. Perry and E. L. Chaffee, Phys. Rev. (2) **36,** 904 (1930) cathode rays. $e/m_0=1.761\cdot 10^7$e.m.u./g
16. A. Upmark, Zeits. f. Physik **55,** 569 (1929)
17. A. R. Olpin, Phys. Rev. (2) **36,** 251 (1930)

IV. Number of Alpha-Particles Z Emitted per Second from 1 Gram Ra

Chief source of error.

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 1/2 percent 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. IIa, **139,** 231, 1930) The theoretical curve is thereby disturbed in the first part of the decay of the preparation so that differences of 1 percent in the value of the active deposit result. This error would cause a minimal value of Z.

Recommended value.

Use of the value $3.7\cdot 10^{10}$ is recommended in accord with reference 9.

Literature.

Literature prior to 1926 in St. Meyer and E. Schweidler, Radioaktivität p. 401.

1. H. Jedrzejowski, Comptes rendus **184,** 1551 (1927); Ann. d. Physique **9,** 128 (1928) $Z=3.50\cdot 10^{10}$
2. I. Curie and F. Joliot, Comptes rendus **187,** 43 (1928) $Z=3.7\cdot 10^{10}$
3. H. J. Braddick and H. M. Cave, Proc. Roy. Soc. **A121,** 368 (1928); Nature **122,** 789 (1928)
   also G. Ortner, Wien. Ber. IIa, **138,** 117 (1929); Mitt. Ra. Inst., 229 $Z=3.69\cdot 10^{10}$
4. F. A. Ward, C. E. Wynn-Williams, H. M. Cave, Proc. Roy. Soc. **A125,** 713 (1929) $Z=3.66\cdot 10^{10}$

5. S. W. Watson and M. C. Henderson, Proc. Roy. Soc. **A118,** 318 (1928) (indirect) $Z=3.72\cdot 10^{10}$
6. G. Hoffmann, Phys. Zeits. **28,** 729 (1927); H. Ziegert, Zeits. f. Physik **46,** 668 (1928) $Z=3.71\cdot 10^{10}$
7. G. Ortner and C. Stetter, Zeits. f. Physik **54,** 475 (1929) $Z=3.72\cdot 10^{10}$
8. L. Meitner and W. Orthmann, Zeits. f. Physik **60,** 143 (1930) $Z=3.68\cdot 10^{10}$
9. E. Rutherford, J. Chadwick and C. D. Ellis, Radiations of Radioactive Substances, 1930, p. 63 $Z=3.70\cdot 10^{10}$

V. Ratio Ra:U in old unaltered Minerals

Recommended value.

The recommended value of Ra/U is:

$$Ra/U=3.4\cdot 10^{-7} \qquad U/Ra=2.94\cdot 10^{6}$$

Literature.

Literature prior to 1926 in St. Meyer and E. Schweidler, Radioaktivität, 1927, p. 398, pp. 404–406, Lit. Nos. 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, J. Amer. Chem. Soc. **36,** 2066 (1914).

VI. Basic Values for the Calculation of the Number of Ion Pairs produced by one Alpha-Particle

$k=k_0R^{2/3}$ and calculation of velocity from $v^3=a_0R_0$

All data refer to 0°C and 760 mm.

As basis for k_0: $Zk=8.18\cdot 10^{15}$ (St. Meyer and E. Schweidler, Radioaktivität, 1927, p. 189)

and $Z=3.7\cdot 10^{10}$

For RaC′: $R_0=6.58$ cm (see table of ranges)

$k=8.18\cdot 10^{15}/3.7\cdot 10^{10}=k_0\cdot 6.58^{2/3}$, $k_0=6.296\cdot 10^4$

Based on $R_0=6.60$ and $Z=3.72\cdot 10^{10}$, $k_0=6.253\cdot 10^4$

Based on $R_0=6.60$ and $Z=3.70\cdot 10^{10}$, $k_0=6.283\cdot 10^4$

Recommended value.

$$k_0=6.3\cdot 10^4$$

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 curve with the abscissa has no theoretical basis.

Element	R_0	v	a_0	$a_0^{1/3}$
RaC′	6.58	$1.022\cdot 10^9$	$1.0790\cdot 10^{27}$	$1.026\cdot 10^9$
ThC′	8.168	2.054	1.0609	1.020
Po	3.67	1.593	1.1015	1.032
		Recommended:	1.08	1.026

The recommended values differ but slightly from the constants now in use which are as follows:

For $R_0=6.60$* $v=1.922\cdot 10^9$ $a_0=1.0758\cdot 10^{27}$ $a_0^{1/3}=1.0246\cdot 10^9$**
(St. Meyer and E. Schweidler, p. 629)

VII. Units

Radium content is expressed gravimetrically in grams or milligrams 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 mm³ at 0°C 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 $2.75\cdot 10^6$ 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.

Eman $=10^{-10}$ curie per liter (10^{-13} curie/cm³) is a term used since 1921 for the Rn content of the atmosphere as a *concentration* unit.

Mache Unit (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 can maintain by its ionization of air a 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 that the use of the term curie be extended to include 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-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 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.

* The basic value 6.60 was the mean of the values: 6.592, G. H. Henderson, Phil. Mag. (6) **42**, 538 (1921) and 6.608, H. Geiger, Zeits. f. Physik **8**, 45 (1921). The value of the range at 15°C corresponding to this value of R_0 is $R_{15}=6.96_3$ cm.

** See Rutherford, Chadwick and Ellis, Reference 9, p. 86.

Polonium.

"1 curie Po" = that amount which, equivalent to 1 g Ra, emits $3.7 \cdot 10^{10}$ α-particles per sec.

"1 curie Po" = quantitiy in radioactive equilibrium with 1 g 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 Po or $0.75 \cdot 10^{-6}$ curie Po.

1 curie Po 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 Po (one sided radiation) 1.33 e.s.u.

Mesothorium.

"1 mg MsTh" usually signifies the γ-ray equivalent of 1 mg 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 St. Meyer and E. Schweidler, 1927, pp. 496–7)—inexact and open to criticsm.

All determinations of content of Ra, Rn, MsTh, Po, etc., must be exactly dated, of course.

VIII. Radioactive Constants

Decay constants.

U_I. For U_I it is to be noted that the calculation is made on the basis $Z = 3.70 \cdot 10^{10} \alpha/\text{sec}$; 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 below are for T and τ upper and for λ lower limits.

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

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

Rn. The two best determinations made recently by W. Bothe, Zeits. f. Physik **16,** 226 (1923); $T = 3.825 \pm 0.003$ days and I. Curie and C. Chamié, Comptes rendus **178,** 1808 (1924); Journ. d. Physique (6) **5,** 328 (1924); $T = 3.823 + 0.002$ 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).

RaE. Earlier accepted value $T = 4.85$ days
L. Bastings, Phil. Mag. **48,** 1075 (1924) 4.985
G. Fournier, Comptes rendus **181,** 502 (1925) 4.86
L. F. Curtiss, Phys. Rev. (2) **27,** 672 (1926) 5.07
J. P. McHutchison, J. Phys. Chem. **30,** 925 (1926) 4.87
Recommended: $T = 5.0$
and $T = 4.9$

RaC′. See references 15, 16, 16a.

ThC′. Mme. Curie has recently calculated from the Geiger-Nuttal Law:

$$\lambda = \text{about } 10^9 \text{ sec}^{-1}.$$

ThC′. In view of the great uncertainty attaching to the values for ThC′, O. Hahn and L. Meitner propose to be content with the statement

$$T < 10^{-6} \text{ sec.}$$

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.

TABLE I. *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.

		T	λ	τ	Literature
Uranium I	UI At. Wt. 238.14 At. No. 92 P. No. 238	$4.4 \cdot 10^9$yr $1.4 \cdot 10^{17}$s	$1.6 \cdot 10^{-10}$yr^{-1} $5.0 \cdot 10^{-18}$s^{-1}	$6.3 \cdot 10^9$ yr $2.0 \cdot 10^{17}$s	cf. "General Remarks" above
Uranium X_1	UX_1 At. No. 90 P. No. 234	24.5d $2.12 \cdot 10^6$s 23.8d $2.06 \cdot 10^6$s	$2.83 \cdot 10^{-2}$d^{-1} $3.28 \cdot 10^{-7}$s^{-1} $2.90 \cdot 10^{-2}$d^{-1} $3.37 \cdot 10^{-7}$s^{-1}	35.4d $3.05 \cdot 10^6$s 34.4d* $2.97 \cdot 10^6$s*	51 1
Uranium X_2 (Brevium) ca 99.65%	UX_2 At. Wt. — At. No. 91 P. No. 234	1.14m 68.4s	0.61m^{-1} $1.01 \cdot 10^{-2}$s^{-1}	1.64m 98.7s	51, 3a 2, 3
Uranium Z ca 0.35%	UZ At. No. 91 P. No. 234	6.7h $2.4 \cdot 10^4$s	0.103h^{-1} $2.87 \cdot 10^{-5}$s^{-1}	9.7h $3.5 \cdot 10^4$s	
Uranium II	UII At. No. 92 P. No. 234	$3 \cdot 10^5$yr $9.4 \cdot 10^{12}$s	$2.3 \cdot 10^{-6}$yr^{-1} $7.4 \cdot 10^{-14}$s^{-1}	$4.3 \cdot 10^5$yr $1.4 \cdot 10^{13}$s	4, 5
Uranium Y ca 3%	UY At. No. 90 P. No. 231 or 230	24.6h 1.03d $8.88 \cdot 10^4$s	$2.82 \cdot 10^{-2}$h^{-1} 0.675d^{-1} $7.81 \cdot 10^{-6}$s^{-1}	35.5h 1.48d $1.28 \cdot 10^5$s	

* Earlier values still in use.

TABLE II. *Ionium-Radium Family*

		T	λ	τ	Literature
Ionium	Io	$8.3 \cdot 10^{4}$yr	$8.3 \cdot 10^{-6}$yr^{-6}	$1.2 \cdot 10^{5}$yr	7, 8, 8a
	At. No. 90	$2.6 \cdot 10^{12}$s	$2.6 \cdot 10^{-13}$s^{-1}	$3.8 \cdot 10^{12}$s	
	P. No. 230				
Radium	Ra	1590 yr	$4.36 \cdot 10^{-4}$yr^{-1}	2295 yr	
	At. No. 88	$5.02 \cdot 10^{10}$s	$1.38 \cdot 10^{-11}$s^{-1}	$7.24 \cdot 10^{10}$s	9
	P. No. 226				
Radon	Rn	3.825d	0.1812d^{-1}	5.518d*	
	At. No. 86	$3.305 \cdot 10^{5}$s	$2.097 \cdot 10^{-6}$s^{-1}	$3.768 \cdot 10^{5}$s*	10
	P. No. 222	3.823d	0.1813d^{-1}	5.515d*	cf. "General Remarks"
		$3.303 \cdot 10^{5}$s	$2.098 \cdot 10^{6}$s^{-1}	$4.765 \cdot 10^{5}$s*	
Radium A	RaA	3.05m	0.227m^{-1}	4.40m	11
	At. No. 84	183s	$3.78 \cdot 10^{-3}$s^{-1}	264s	51
	P. No. 218				
Radium B	RaB	26.8m	$2.59 \cdot 10^{-2}$m^{-1}	38.7m	
	At. No. 82	$1.61 \cdot 10^{3}$s	$4.31 \cdot 10^{-4}$s^{-1}	$2.32 \cdot 10^{3}$s	
	P. No. 214				
Radium C	RaC	19.7m	$3.51 \cdot 10^{-2}$m^{-1}	28.5m	
	At. No. 83	$1.18 \cdot 10^{3}$s	$5.86 \cdot 10^{-4}$s^{-1}	$1.17 \cdot 10^{3}$s	12
	P. No. 214				
Radium C′	RaC′	ca 10^{-6}s	10^{6}s^{-1}	10^{-6}s	13, 14
99.96%	At. No. 84				15, 16
(99.97%)	P. No. 214				16a
Radium C″	RaC″	1.32m	0.525m^{-1}	1.9m	
0.04%	At. No. 81	79.2s	$8.7 \cdot 10^{-3}$s^{-1}	115s	17
(0.03%)	P. No. 210				
Radium D	RaD	22yr	0.0315yr^{-1}	31.7yr	
	At. No. 82	$6.94 \cdot 10^{8}$s	$1.00 \cdot 10^{-9}$s^{-1}	$1.00 \cdot 10^{9}$s	18, 19, 20
	P. No. 210				
Radium E	RaE	4.9d	0.141d^{-1}	7.07d*	
		$4.26.10^{5}$s	$1.63 \cdot 10^{-6}$s^{-1}	$6.13 \cdot 10^{5}$s*	21
	At. No. 83	5.0d	0.139d^{-1}	7.2d*	
	P. No. 210	$4.32 \cdot 10^{5}$s	$1.61 \cdot 10^{-6}$s^{-1}	$6.22 \cdot 10^{5}$s*	
Radium F	RaF(Po)	140d	$4.95 \cdot 10^{-3}$d^{-1}	202d	22, 23
Polonium	At. No. 84	$1.21 \cdot 10^{7}$s	$5.73 \cdot 10^{-8}$s^{-1}	$1.75 \cdot 10^{7}$s	
	P. No. 210				
Radium G	RaG				
(uranium	At. Wt. 206.016				
lead)	At. No. 82				
	P. No. 206				

* Earlier values still in use.

TABLE III. *Actinium Family*

		T	λ	τ	Literature
Actinium Uranium	AcU	ca 10^8 to 10^9 yr			24
Uranium Y (see Uranium Family)					24a
Protactinium	Pa At. No. 91 P. No. 231	$3.2\cdot10^4$yr $1.01\cdot10^{12}$s	$2.17\cdot10^{-5}$yr^{-1} $6.86\cdot10^{-13}$s^{-1}	$4.6\cdot10^4$yr $1.46\cdot10^{12}$s	25
Actinium	Ac At. No. 89 P. No. 227	13.5yr $4.23\cdot10^8$s 20 yr $6.3\cdot10^8$s	$5.15\cdot10^{-2}$yr^{-1} $1.63\cdot10^{-9}$s^{-1} $3.4\cdot10^{-2}$yr^{-1} $1.1\cdot10^{-9}$s^{-1}	19.4yr $6.12\cdot10^8$s 29 yr* $9.2\cdot10^8$s*	26
Radio-actinium	RdAc At. No. 90 P. No. 227	18.9d $1.63\cdot10^6$s	$3.66\cdot10^{-2}$d^{-1} $4.24\cdot10^{-7}$s^{-1}	27.3d $2.36\cdot10^6$s	27, 28
Actinium X	AcX At. No. 88 P. No. 223	11.2d $9.7\cdot10^5$s 11.4d $9.85\cdot10^5$s	$6.17\cdot10^{-2}$d^{-1} $7.14\cdot10^{-7}$s^{-1} $6.08\cdot10^{-2}$d^{-1} $7.06\cdot10^{-7}$s^{-1}	16.2d* $1.40\cdot10^6$s* 16.4d* $1.42\cdot10^6$s*	27, 51
Actinon	An At. No. 86 P. No. 219	3.92s	0.177s^{-1}	5.66s	29, 51
Actinium A	AcA At. No. 84 P. No. 215	$2\cdot10^{-3}$s	374s^{-1}	$2.88\cdot10^{-3}$s	30
Actinium B	AcB At. No. 82 P. No. 211	36.0m $2.16\cdot10^3$s	$1.93\cdot10^{-2}$m^{-1} $3.21\cdot10^{-4}$s^{-1}	51.9m $3.12\cdot10^3$s	31
Actinium C	AcC At. No. 83 P. No. 211	2.16m 130s	0.321m^{-1} $5.35\cdot10^{-3}$s^{-1}	3.12m 187s	27
Actinium C′ 0.32%	AcC′ At. No. 84 P. No. 211	ca $5\cdot10^{-3}$s	ca 140s^{-1}	ca $7\cdot10^{-3}$s	
Actinium C″ 99.68%	AcC″ At. No. 81 P. No. 207	4.76m 286s 4.71m 283s	0.145m^{-1} $2.43\cdot10^{-3}$s^{-1} 0.146m^{-1} $2.44\cdot10^{-3}$s^{-1}	6.87m* 412s* 6.83m* 410s	32
Actinium D Actinium Lead Pb207	AcD At. Wt. 207.016 (?) At. No. 82 P. No. 207				

TABLE IV. *Thorium Family*

		T	λ	τ	Literature
Thorium	Th At. Wt. 232.12 At. No. 90 P. No. 232	$1.8\cdot 10^{10}$yr $5.6\cdot 10^{17}$s	$4.0\cdot 10^{-11}yr^{-1}$ $1.2\cdot 10^{-18}s^{-1}$	$2.5\cdot 10^{10}$yr $8.0\cdot 10^{17}$s	33
Mesothorium 1	$MsTh_1$ At. No. 88 P. No. 228	6.7yr $2.1\cdot 10^{8}$s	$0.103yr^{-1}$ $3.26\cdot 10^{-9}s^{-1}$	9.7yr $3.05\cdot 10^{8}$s	
Mesothorium 2	$MsTh_2$ At. No. 89 P. No. 228	6.13h $2.21\cdot 10^{4}$s	$0.113h^{-1}$ $3.14\cdot 10^{-5}s^{-1}$	8.84h $3.18\cdot 10^{4}$s	34
Radiothorium	RdTh At. No. 90 P. No. 228	1.90yr $6.0\cdot 10^{7}$s	$0.365yr^{-1}$ $1.16\cdot 10^{-8}s^{-1}$	2.74yr $8.65\cdot 10^{7}$s	35
Thorium X	ThX At. No. 88 P. No. 224	3.64d $3.14\cdot 10^{5}$s	$0.190d^{-1}$ $2.20\cdot 10^{-6}s^{-1}$	5.25d $4.54\cdot 10^{5}$s	
Thoron	Tn At. No. 86 P. No. 220	54.5s	$1.27\cdot 10^{-2}s^{-1}$	78.7s	36
Thorium A	ThA At. No. 84 P. No. 216	0.14s	$4.95s^{-1}$	0.20s	37
Thorium B	ThB At. No. 82 P. No. 212	10.6h $3.82\cdot 10^{4}$s	$6.54\cdot 10^{-2}h^{-1}$ $1.82\cdot 10^{-5}s^{-1}$	15.3h $5.51\cdot 10^{4}$s	
Thorium C	ThC At. No. 83 P. No. 212	60.5m $3.63\cdot 10^{3}$s	$1.15\cdot 10^{-2}m^{-1}$ $1.91\cdot 10^{-4}s^{-1}$	87.3m $5.24\cdot 10^{3}$s	38
Thorium C′ 65% 65.7%	ThC′ At. No. 84 P. No. 212	10^{-9}s (?) $<10^{-6}$s	$10^{9}s^{-1}$ (?) $>10^{6}s^{-1}$	10^{-9}s (?) $<10^{-6}$s	 40
Thorium C″ 35% 34.3%	ThC″ At. No. 81 P. No. 208	3.1m 186s	$2.24\cdot 10^{-1}m^{-1}$ $3.73\cdot 10^{-3}s^{-1}$	4.47m 286.3s	39 40
Thorium D Thorium lead Pb208	ThD At. Wt. 208.016 (?) At. No. 82 P. No. 208				

TABLE V. *Quantities in Radioactive Equilibrium*

		T	M (mass units) for Ra = 1	for UI = 1
	UI	$1.39\cdot 10^{17}$s	$2.94\cdot 10^{6}$	1.00
	UX_1	$2.12\cdot 10^{6}$	$4.4\cdot 10^{-5}$	$1.5\cdot 10^{-11}$
		$(2.06)10^{6}$	$(4.3)10^{-5}$	
99.65%	UX_2	68.4	$1.4\cdot 10^{-9}$	$5\cdot 10^{-16}$
0.35%	UZ	$2.4\cdot 10^{4}$	$1.7\cdot 10^{-8}$	6.10^{-16}
	UII	$9.4\cdot 10^{12}$	$2.0\cdot 10^{2}$	$6.7\cdot 10^{-5}$
3%	UY	$8.88\cdot 10^{4}$	$5.6\cdot 10^{-8}$	$1.9\cdot 10^{-14}$
97%	Io	$2.6\cdot 10^{12}$s	52.7	
	Ra	$5.02\cdot 10^{10}$	1.00	
	Rn	$3.303\cdot 10^{5}$	$6.47\cdot 10^{-6}$	
	RaA	183	$3.52\cdot 10^{-9}$	
	RaB	$1.61\cdot 10^{3}$	$3.04\cdot 10^{-8}$	
	RaC	$1.18\cdot 10$	$2.23\cdot 10^{-8}$	
99.96%	RaC′	ca 10^{-6}	ca $2\cdot 10^{-19}$	
0.04%	RaC″	79.2	$6\cdot 10^{-13}$	
	RaD	$6.94\cdot 10^{8}$	$1.28\cdot 10^{-2}$	
	RaE	$4.26\cdot 10^{5}$ (4.9d)	$7.9\cdot 10^{-6}$	
		$4.32\cdot 10^{5}$ (5.0d)	$8.0\cdot 10^{-6}$	
	Po = RaF	$1.21\cdot 10^{7}$	$2.24\cdot 10^{-4}$	
			M for Ra = 1 and 3% branching fraction	
	Pa	$1.01\cdot 10^{12}$s	0.62	
	Ac	$4.23\cdot 10^{8}$	$2.5\cdot 10^{-4}$	
		$(6.3\cdot 10^{8}=20\text{yr})$	$(3.7\cdot 10^{-4})$	
	RdAc	$1.63\cdot 10^{6}$	$9.8\cdot 10^{-7}$	
	AcX	$9.7\cdot 10^{5}$	$5.8\cdot 10^{-7}$	
	An	3.92	$2.27\cdot 10^{-12}$	
	AcA	$2\cdot 10^{-3}$	$1.14\cdot 10^{-15}$	
	AcB	$2.16\cdot 10^{-3}$	$1.21\cdot 10^{-9}$	
	AcC	130	$7.2\cdot 10^{-11}$	
0.32%	AcC′	ca 10^{-3}	ca $2\cdot 10^{-18}$	
99.68%	AcC″	286	$1.57\cdot 10^{-10}$	
		(283)	$1.55\cdot 10^{-10}$	

TABLE VI. *Quantities in Radioactive Equilibrium*

		T	M (mass units) for Th = 1	for $MsTh_1$ = 1
	Th	$5.6\cdot 10^{17}$s	1.00	$2.7\cdot 10^{9}$
	$MsTh_1$	$2.1\cdot 10^{8}$	$3.68\cdot 10^{-10}$	1.00
	$MsTh_2$	$2.21\cdot 10^{4}$	$3.88\cdot 10^{-14}$	$1.05\cdot 10^{-4}$
	RdTh	$6.0\cdot 10^{7}$	$1.05\cdot 10^{-10}$	0.286
	ThX	$3.14\cdot 10^{5}$	$5.41\cdot 10^{-13}$	$1.47\cdot 10^{-3}$
	Tn	54.5	$9.23\cdot 10^{-17}$	$2.50\cdot 10^{-7}$
	ThA	0.14	$2.32\cdot 10^{-19}$	$6.31\cdot 10^{-10}$
	ThB	$3.82\cdot 10^{4}$	$6.23\cdot 10^{-14}$	$1.69\cdot 10^{-4}$
	ThC	$3.63\cdot 10^{3}$	$5.92\cdot 10^{-15}$	$1.61\cdot 10^{-5}$
65%	ThC′	ca 10^{-9}	ca 10^{-27}	ca $3\cdot 10^{-18}$
		or 10^{-6}	10^{-14}	$3\cdot 10^{-15}$
35%	ThC″	186	$1.04\cdot 10^{-16}$	$2.83\cdot 10^{-7}$

Ranges, velocities and ion productions.

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 431.

TABLE VII. *Ranges at 0°C and 760 mm Hg in Air* (R_0); *at 15°C* (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-Sch, 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-Sch, 41
Ra	3.21	3.39	1.51	1.36^+	42
Rn	3.91	4.12	1.61	1.55	M-Sch
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-Sch
	(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-Sch
RdAc	4.43	4.68	1.68	1.69	52
	and 4.77	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	5.09	1.73	1.79	
AcC′	(6.2)?	(6.5)?	(1.9)?	ca 2	

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, Zeits. f. Physik **8,** 45 (1921) supplemented by those of G. H. Henderson, Phil. Mag. (6) **42,** 538 (1921) and the later values (reference 41) are the ones used in the following. For U_{II} see the note on page 433.

For RaC′ Mmes. M. Curie and I. Joliot-Curie have made the following summary:

H. Geiger, Zeits. f. Physik **8,** 45 (1921)	$R_{15}=6.971$ cm
G. H. Henderson, Phil. Mag. (6) **42,** 538 (1921)	$R_{15}=6.953$ cm
I. Curie and F. Béhounek, J. d. Physique et le Radium **7,** 125 (1926)	$R_{15}=6.96$ cm
G. I. Harper and E. Salaman, Proc. Roy Soc. **A127,** 175 (1930)	$R_{15}=6.94$ cm
Recommended value	$R_{15}=6.95$ or 6.96 cm

Since the basic value for RaC′ which has been used up to the present (cf. page 431) 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, Comptes rendus **190,** 1124 (1930) and the sections in Rutherford, Chadwick and Ellis (reference 51) page 82ff 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 values for ion production by α-particles is that for RaC′: $k = 2.2 \cdot 10^5$.

For the velocity of α-particles from ThC, Rutherford, Chadwick and Ellis (reference 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.

Literature on decay constants and ranges.

For literature prior to 1926 see St. Meyer and E. Schweidler, Radioaktivität, 1927 (cited as M-Sch)

1. G. Kirsch, Mitt. Ra. Inst. 127, Wien. Ber. IIa, **129,** 309 (1920), M-Sch. p. 377.	
2. O. Hahn and L. Meitner, Phys. Zeits. **14,** 758 (1913)	$T = 1.17$ m for UX_2
3. W. G. Guy and A. S. Russell, J. Amer. Chem. Soc. **123,** 2618 (1923)	$T = 1.175$ m for UX_2
3a. E. Stahel, Diss. Zürich, 1922	$T = 1.138$ m for UX_2
4. G. Hoffmann, Phys. Zeits. **28,** 729 (1927); H. Ziegert, Zeits. f. Physik **46,** 668 (1928); (Calculated for $\log \lambda = -41.6 + 60.4 \log R_0$)	
5. G. C. Laurence, Phil. Mag. (7) **5,** 1027 (1927)	$T = 1.5 \cdot 10^4$ yr for UII
6. For atomic weight determinations of U, Ra, RaG see St. Meyer, Mitt. Ra. Inst. 226, Wien. Ber. IIa, **137,** 599 (1928)	
7. F. Soddy, Phil. Mag. (6) **38,** 483 (1919)	$T = 108000$ yr for Io
7a. F. Soddy and A. F. R. Hitchens, Phil. Mag. (6) **47,** 1148 (1924). The same T in round numbers	$T = 1.1 \cdot 10^5$ yr for Io
8. St. Meyer, Mitt. Ra. Inst. 88, 121 and 158 Wien. Ber. IIa, **125,** 191 (1916), **128,** 897 (1919), **132,** 279 (1923)	$T = 130{,}000$ yr for Io
Average of values of T in references 7 and 8	$T = 1.2 \cdot 10^5$ yr for Io
8a. M. Curie and S. Cotelle, Comptes rendus **190,** 1289 (1930); M. Curie, J. Chim. Phys. **27,** 347 (1930)	$T = 1.19 \cdot 10^5$ yr for Io

9. For $Z = 3.72 \cdot 10^{10}$ $3.70 \cdot 10^{10}$ $3.68 \cdot 10^{10}$
$T = 1582$ 1591 1600 yr for radium
10. M-Sch, p. 417, 418.
11. M. Blau, Mitt. Ra. Inst. 161, Wien. Ber. IIa, **133,** 17 (1924)
12. P. Bracelin, Proc. Camb. Phil. Soc. **23,** 150 (1926)
13. M-Sch, p. 51.
14. M-Sch, p. 466.
15. J. C. Jacobson, Phil. Mag. (6) **47,** 23 (1924) — $T = 0.83 \cdot 10^{-6}$ sec. for RaC′
16. A. W. Barton, Phil. Mag. (7) **2,** 1273 (1926) — $T =$ ca 10^{-6} sec. for RaC′
16a. F. Joliot, Comptes rendus **191,** 132 (1930) — $T = 3 \cdot 10^{-6}$ sec. for RaC′
17. E. Albrecht, Mitt. Ra. Inst. 123, Wien. Ber. IIa **128,** 925 (1919)
18. E. Schweidler, Wien. Ber. IIa, **138,** 743 (1929)
19. M. Curie and I. Joliot-Curie, J. d. Physique (6) **10,** 385 (1929)
20. I. Joliot-Curie, J. d. Physique, **10,** 388 (1929)
21. Average. See M-Sch, p. 446 and also L. F. Curtiss, Phys. Rev. (2) **30,** 539 (1927) — $T = 4.975$ d for RaE
22. M-Sch, p. 453.
23. M. A. da Silva, Comptes rendus **184,** 197 (1927)
24. E. Rutherford, Nature **123,** 313 (1929) — $T = 4.2 \cdot 10^{8}$ yr for AcU
24a. A. Holmes, Nature **126,** 348 (1930). *T* for AcU same order of magnitude as for UI.
24b. A. F. Kovarik, Science **72,** 122 (1930), Phys. Rev. (2) **35,** 1432 (1930) — $T = 2.7 \cdot 10^{8}$ yr for AcU
25. A. v. Grosse, Ber. Chem. Ges. **61,** 233 (1928); Naturwiss. **15,** 766 (1927); Nature **120,** 621 (1927)
O. Hahn and A. v. Grosse, Zeits. f. Physik **48,** 1, 600 (1928) — $T = 20200$ yr for Pa
O. Hahn and E. Walling, Naturwiss. **15,** 803 (1928)
E. Walling, Diss. Berlin, (1928) — $T = 20760$ yr for Pa
A. v. Grosse, J. Amer. Chem. Soc. **52,** 1742 (1930) — $T = 3.2 \cdot 10^{4}$ yr for Pa
26. St. Meyer, Mitt. Ra. Inst. 218, Wien. Ber. IIa, **137,** 235 (1928)

27. St. Meyer and F. Paneth, Mitt. Ra. Inst. 104, Wien. Ber. IIa, **127,** 147 (1918). M-Sch, pp. 475 and 477.	
28. L. Imre, Zeits f. Anorg. Chem. **166,** 1 (1927)	
29. M. Leslie, Phil. Mag. (6) **24,** 637 (1921)	
P. B. Perkins, Phil. Mag. (6) **27,** 720 (1914)	
R. Schmid, Mitt. Ra. Inst. 103, Wien. Ber. IIa, **126,** 1065 (1917)	$T = 3.92$ sec. for An
30. H. G. T. Moseley and K. Fajans, Phil. Mag. (6) **22,** 629 (1911)	$\lambda = 347$ for AcA
H. Ikeuti, Nageoka Festschr., Tokio, 295 (1925)	$T = 0.0015$ sec. for AcA
M. Akiyama, Comptes rendus **187,** 341 (1928)	$T = 1.93 \cdot 10^{-3}$ sec. for AcA
31. M-Sch, p. 482.	
32. O. Hahn and L. Meitner, 1908	$T = 5.1$ min. for AcC″
A. F. Kovarik, 1911	$T = 4.71$ min. for AcC″
E. Albrecht, 1919 (cf. M-Sch, p. 483)	$T = 4.76$ min. for AcC″
33. H. N. McCoy, Phys. Rev. (2) **1,** 403 (1913)	$T = 1.78 \cdot 10^{10}$ yr for Th
G. Kirsch, Mitt. Ra. Inst. 150, Wien. Ber. IIa, **131,** 55 (1922), Naturwiss. **11,** 372 (1923). The values reported then are revised and have been improved by the Pb method and measurement with a tube electrometer. G. Kirsch, Phys. Zeits. **31,** 1017 (1930), Naturwiss. **18,** 1054 (1930)	$T = 1.65\text{–}1.8 \cdot 10^{10}$ yr for Th
34. O. Hahn and O. Erbacher, Phys. Zeits, **27,** 531 (1926)	
35. St. Meyer and F. Paneth, Mitt. Ra. Inst. 96, Wien. Ber. IIa, **125,** 1253 (1916)	
B. Walter, Phys. Zeits. **18,** 584 (1917)	
L. Meitner, Phys. Zeits. **19,** 257 (1918), agreeing	$T = 1.90$ yr for RdTh
36. P. B. Perkins, Phil. Mag. (6) **27,** 720 (1914)	
R. Schmid, Mitt. Ra. Inst. 103, Wien. Ber. IIa, **126,** 1065 (1917), agreeing	$T = 54.5$ sec. for Tn
37. Moseley–Fajans, reference 30, in the text	$T = 0.145$ sec. for ThA
in the summary	$T = 0.14$ sec. for ThA
38. F. v. Lerch, Wien. Ber. IIa, **123,** 699 (1914) cf. M-Sch, p. 509	

39. O. Hahn and L. Meitner, 1909 — $T = 3.1$ min. for ThC″
F. v. Lerch and E. v. Lartburg, 1909 — $T = 3.0$ min. for ThC″
E. Albrecht, 1919, cf. M-Sch, p. 513 — $T = 3.2$ min. for ThC″
40. L. Meitner and K. Freitag, Naturwiss. **12**, 634 (1924)
Zeits. f. Physik **37**, 481 (1926), **38**, 574 (1926). Branching fraction 65.7 and 34.3 percent.
41. G. C. Laurence, Trans. Nova Scotia Inst. 1927, Phil. Mag. (7) **5**, 1027 (1928)
42. G. Hoffmann, Phys. Zeits. **28**, 729 (1927)
H. Ziegert, Zeits. f. Physik **46**, 668 (1928)
43. E. Rutherford, Phil. Mag. (7) **4**, 580 (1927)
44. G. J. Harper and E. Salaman, Proc. Roy. Soc. **A127**, 175 (1930)
44a. I. Curie and F. Béhounek, J. d. Physique et le Radium **7**, 125 (1926)
45. I. Curie, Comptes rendus **175**, 220 (1922)
46. F. Joliot and T. Oneda, J. d. Physique et le Radium **9**, 175 (1928)
47. J. L. Nickerson, Trans. Nova Scotia Inst. **17**, 172 (1929)
47a. G. H. Henderson and J. L. Nickerson, Phys. Rev. (2) **36**, 1344 (1930)
48. G. H. Briggs, Proc. Roy. Soc. **A118**, 549 (1928)
48a. E. Rutherford, F. A. B. Ward and C. E. Wynn-Williams, Proc. Roy. Soc. **A129**, 211 (1930)
49. G. C. Laurence, Proc. Roy. Soc. **A122**, 543 (1929)
50. E. Walling, Zeits. f. Phys. Chem. (B) **10**, 467 (1930)
51. E. Rutherford, J. Chadwick and C. D. Ellis, Radiations from Radioactive Substances, 1930.
52. St. Meyer, V. F. Hess and F. Paneth, Wien. Ber. IIa, **123**, 1459 (1914)
I. Curie, Comptes rendus **192**, 1102 (1931)

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.

TABLE VIII. *Beta-Rays*[28]

Substance	Type of decay	μ cm^{-1} Al	μ/ρ	D cm Al	Literature	Magnetic spectrum velocity limits in 10^{10} cm/sec.	Remarks	Accompanying γ-rays
UX_1	β	460	170	0.0015	9	1.44–1.74	3L, 1B*	no nuclear γ-rays
UX_2	β	18	6.75	0.038	9	2.46–2.88	2B	weak nuclear γ-rays
UZ	β	270 to 36	100 to 13.5	0.0026 to 0.019	11	?	?	?
Ra	α	312	116	0.00222	4	1.56–2.04	3L	1 nuclear γ-line
RaB	β	890	330	0.00078	1	1.08–2.17	31L	9 nuclear γ-lines
		80	29.5	0.0087				
		13	4.84	0.053				
RaC+C″	$\alpha+\beta$	50	18.5	0.0139	1	1.14–2.96	63L	11 nuclear γ-lines
		13	4.84	0.053				
RaD	β	5500	2037	0.000126	8	0.96–1.20	5L	1 nuclear γ-line
RaE	β	45.5	16.9	0.0152	13	2.05–2.84	1B	weak nuclear γ-ray
UY	β	ca 300	110	0.0023	10	?	?	?
Pa	α	126	47	0.0055	14, 16	1.47–2.35	12L	3 nuclear γ-lines
Ac	β	?	?	?		?		?
RdAc	α	175	65	0.004	14	0.66–2.3	49L	10 γ-lines
AcX	α	?	?	?		0.88–2.22	21L	5 γ-lines
AcB	β	ca 1000	370	0.0007	2	1.49	1L?	
AcC+C″	$\alpha+\beta$	29	10.7	0.024	5	2.25–2.56	8L	3 nuclear γ-lines
$MsTh_1$	β	?	?	?		?	?	?
$MsTh_2$	β	40 to 20	14.8 to 7.4	0.018 to 0.034	3	1.09–2.90	31L	8 γ-lines
RdTh	α	420	150	0.0017	6	1.19–1.53	6L	2 γ-lines
ThB	β	153	57	0.0045	5, 7	1.88–2.99	5L	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	37L	11 nuclear γ-lines
K	β	74	27.4	0.0094	15			weak γ-rays
		49	18	0.014				
Rb	β	700	260	0.001	15, 19			
		190	70	0.0037				
		900	333	0.0077	12			

Bands originate in the primary (nuclear) beta rays; lines in the photo-electrons of the gamma rays.

* L = line, B = band.

TABLE IX. *Gamma-Rays*

μ is arranged to show the assumed origin of the radiation

Substance	Type of Decay	Values of μ				
		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		
Ra	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
RaE	β				0.24	(Lit. 22)
RaF	α	2700	46		like RaC	Reference 20, 21
Pa	α					3 (reference 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 (reference 17)
ThB	β	160	32	0.36		3
ThC″	β				0.096	11
K	β		from $\mu_{Fe}=0.19$		0.065	reference 18
			from $\mu_{Pb}=0.59$		0.14	reference 19

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