The Journal of the American Chemical Society

with which has been incorporated
The American Chemical Journal
(Founded by Ira Remsen)

VOL. 45 APRIL, 1923 No. 4

REPORT OF THE INTERNATIONAL COMMITTEE ON CHEMICAL ELEMENTS

1923

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Constitution of the Committee

The International Committee on Atomic Weights takes its instructions from the International Association of Chemical Societies which was dissolved during the Great War and replaced by the International Union of Pure and Applied Chemistry.

During the second Conference, held at Brussels on June 30, 1921, the International Union of Pure and Applied Chemistry decided to replace the International Committee on Atomic Weights by an International Committee on Chemical Elements. The scope of the new Committee is more extended than that of the old Committee. The discovery of isotopy first in the domain of radioactive elements, later in that of non-radioactive elements, produced new problems not only concerning atomic weights, but also affecting the conception of a chemical element.

In consequence, the International Union has decided that it should be the duty of the new Committee to keep chemists informed of the various advances made each year in this field already rich and so full of promise for the future.

The Committee will therefore prepare three tables: a table of radioactive elements containing their principal constants, a table of isotopes, and a table of atomic weights.

In accordance with its statutes the Committee has invited all the national branches of the International Union to create in their countries national

committees from which it may receive notice on any question connected with its activities. Three of these national committees are actually working, in Spain, France and Switzerland.

Work of the Committee during the Year 1921-1922

The Committee has prepared the two tables, of which the need was particularly felt: a Table of Radioactive Elements and a Table of Isotopes.

The work of the Committee is not complete as regards the Table of Atomic Weights which will be published later on. As a result, the Table for 1922 drawn up by the old International Committee for Atomic Weights is accepted for 1923. It is on this account that the values which appear in the Table of Isotopes under the title Atomic Weights are those given in the International Table for 1922.

In the case of the radioactive elements, the figures appearing under the title Atomic Mass are the values, rounded to the nearest whole number, from the atomic weights of uranium (uranium I), thorium and radon (radium emanation). The Committee has found it necessary to modify the nomenclature of several radioactive elements.

Each of the tables is accompanied by notes which explain the signs, symbols and new names adopted by the Committee.

The Committee considers that, as regards the radioactive elements and isotopes, its work is only provisional. It recognized that the definitions and nomenclatures which have been adopted do not form a homogeneous whole. Until a general reform of the nomenclature of the radioactive elements is under consideration it has respected as far as possible the names given by the discoverers. On this account, before adopting for the three emanations the names radon, actinon and thoron, the approval of Mme. Curie and Sir E. Rutherford was obtained.

The Committee hopes that the new international tables will be favorably received by the scientific world, and that the values adopted will be generally approved.

International Table of Isotopes

1923

Atomic Number.—A chemical element is defined by its atomic number. This number represents the excess of positive over negative charges in the constitution of the atomic nucleus; theoretically, the atomic number represents also the number of electrons which rotate round the central positive nucleus of the atom. Each atomic number also represents the place occupied by the element in the Mendeleef table.

Various methods have been suggested to determine the atomic numbers. The most important of these consists in deducing them from the wave lengths of the high-frequency spectra by applying Moseley's law.

Elements (Simple and Complex). Isotopes.—If the above definition is accepted, each chemical element may be simple or complex, according as its atoms are all of equal mass or not.

International Table of Isotopes, 1923

ELEMENT	ATOMIC number	ATOMIC WEIGHT[a]	Maximum NUMBER of Isotopes	MASSES of ISOTOPES[b]	% ACCURACY	OBSERVER	REFERENCE
H	1	1.008	1	1.008	0.2	A.	3 ; 5
He	2	4.00	1	4	0.2	A.	3 ; 5
Li	3	6.94	2	7 ; 6		A., T., D.	9 ; 10 ; 14 ; 16
Gl	4	9.1	1	9		T.	17
B	5	10.9	2	11 ; 10	0.1	A.	6 ; 7
C	6	12.005	1	12		A.	2 ; 5
N	7	14.008	1	14	0.2	A.	3 ; 5
O	8	16.000	1	16		A.	2 ; 5
F	9	19.0	1	19	0.1	A.	6 ; 7
Ne	10	20.2	2	20 ; 22	0.1	A.	1 ; 4 ; 5
Na	11	23.00	1	23		A.	11 ; 14
Mg	12	24.32	3	24 ; 25 ; 26		D.	15 ; 16
Al	13	27.0	1	27		A.	21
Si	14	28.1	2	28 ; 29 ; (30)	0.1	A.	6 ; 7
P	15	31.04	1	31	0.2	A.	6 ; 7
S	16	32.06	1	32	0.2	A.	6 ; 7
Cl	17	35.46	2	35 ; 37	0.1	A.	2 ; 5 ; 13
A	18	39.9	2	40 ; 36	0.1	A.	3 ; 5 ; 8
K	19	39.10	2	39 ; 41		A.	11 ; 14
Ca	20	40.07	(2)	40 ; (44)		D.	18
Fe	26	55.84	(1)	56 ; (54) ?	see ref.	A.	19
Ni	28	58.68	2	58 ; 60	0.1	A.	12
Zn	30	65.37	4	64 ; 66 ; 68 ; 70		D.	18
As	33	74.96	1	75	0.1	A.	6 ; 7
Se	34	79.2	6	80; 78; 76; 82; 77; 74	0.1	A.	21
Br	35	79.92	2	79 ; 81	0.1	A.	6 ; 7
Kr	36	82.92	6	84; 86; 82; 83; 80; 78	0.1	A.	3 ; 5
Rb	37	85.45	2	85 ; 87		A.	11 ; 14
Sn	50	118.7	7 (8)	120 ; 118 ; 116 ; 124 119 ; 117 ; 122 ; (121)	see ref.	A.	20
I	53	126.92	1	127	0.2	A.	8 ; 13
Xe	54	130.2	7 (9)	129;132;131;134;136; 128; 130; (126); (124)	0.1	A.	3; 5; 8; 13; 21
Cs	55	132.81	1	133		A.	11 ; 14
Hg	80	200.6	(6)	(197-200) ; 202 ; 204	0.1	A.	2 ; 3 ; 5

1. *Nature*, November 27, 1919.
2. *Nature*, December 18, 1919.
3. *Nature*, March 4, 1920.
4. *Philosophical Magazine*, April, 1920.
5. *Philosophical Magazine*, May, 1920.
6. *Nature*, July 1, 1920.
7. *Philosophical Magazine*, November, 1920.
8. *Nature*, December 9, 1920.
9. Aston and Thomson, *Nature*, February 24, 1921.
10. Dempster, *Science*, April 15, 1921.
11. Aston, *Nature*, March 17, 1921.
12. Aston, *Nature*, June 23, 1921.
13. Aston, *Philosophical Magazine*, July, 1921.
14. Aston, *Philosophical Magazine*, September, 1921.
15. Dempster, *Science*, December 19, 1921.
16. Dempster, *Phys. Review*, December, 1921.
17. G.-P. Thomson, *Philosophical Magazine*, November, 1921.
18. Dempster, *Phys. Review*, 19; p. 431; 1922.
19. Aston, *Nature*, September 2, 1922.
20. Aston, *Nature*, June 24, 1922.
21. Aston, *Nature*, November 18, 1922.

Observers : A = Aston, D = Dempster, T = Thomson (G. P.)

[a] International values for 1922.

[b] In order of intensity of spectral bands.

In the latter case, the element consists of as many isotopes as its atoms have different masses. A complex element is a mixture of isotopes. Three methods (J. J. Thomson, Aston, Dempster) have been devised to determine isotopes. The most important is that of Aston.

Notation.—The elements, simple or complex, are represented by the ordinary symbols. To indicate any particular isotope, its atomic mass[1] is written as an index to the right of the symbol representing the mixture. Thus, Cl^{35} indicates the isotope of chlorine having an atomic mass 35. This number represents the relative mass of its atom, the atom of oxygen (a simple element) being taken as 16.

Elements Included in the Table.—The isotopes of lead, which are the ultimate result of disintegration of radioactive elements, and the radioactive isotopes will appear only in the International Table of the Radioactive Elements. Only those elements appear in the Table of Isotopes which are recognized as simple, or are complex elements whose isotopes have been determined with sufficient certainty.

Provisional Values.—Numbers in brackets are to be taken as provisional only.

International Table of the Radioactive Elements and their Constants

1923

Remarks Concerning the Nomenclature

It is desirable that the nomenclature adopted by the International Commission should be accepted universally, but that now put forward for the present year is provisional, designed to serve as a basis of discussion with a view to the ultimate adoption of a standard nomenclature.

The most important points are: (1) the three radioactive emanations have been given the names radon, actinon and thoron, with the symbols Rn, An, Tn, to suggest both their origin and their chemical character as members of the family of the rare gases of which the valence is zero; (2) in the branches which occur at the C members the sign (′) has been used to indicate the products resulting from the emission of β-rays (isotopes of polonium) and the sign (″) to indicate the products resulting from the emission of α-rays (isotopes of thallium); (3) the ultimate products have been indicated by the letter Ω.

Note 1.— *Uranium I.* The value given for θ is that obtained from the equation, $\theta = 1/\lambda = 2440 \times 0.97 \times 3 \times 10^6 \times (226/238) = 6.75 \times 10^9$, in which 2440 represents the average life of radium in years, 0.97 the branching coefficient and $3 \times 10^6 \times (226/238)$ the ratio between the numbers of atoms of uranium and radium in equilibrium in minerals.

[1] The expression "atomic mass" is reserved for isotopes or simple elements considered from the isotopic point of view. The expression "atomic weight" retains its usual meaning, and is applied to elements without consideration of their isotopic constitution.

If the actinium series is independent from that of uranium I, λ cannot be calculated by this method.

The value of λ obtained by the direct counting of the α-particles from a compound of uranium is 4.57×10^{-18}, from which $\theta = 7 \times 10^9$ years and $T = 4.8 \times 10^9$ years.

Note 2.— *Uranium* X_2 is also called brevium.

Note 3.—*Radon* replaces the names *radium emanation* and *niton* (the latter was proposed by Sir William Ramsay).

Note 4.—*Radium C* undergoes a double disintegration; 99.97% of the atoms emit β-rays and produce the substance RaC′ which gives α-rays, and 0.03% of the atoms emit α-rays and produce the substance RaC″ which gives β-rays.

Note 5.—*Radium D* is also called radiolead.

Note 6.—*Radium C″* is also called radium C_2.

Note 7.— *Uranium Y* is the first known member of the actinium series. It may be derived from uranium I or uranium II. In this case, 3% of the atoms of uranium produce the actinium family, and 97% the radium family.

The hypothesis has also been put forward that the actinium series may be produced independently from a third (hypothetical) isotope of uranium for which the name actino-uranium has been proposed.

Note 8.—*Protoactinium* is also called eka-tantalum.

Note 9.—A new radioactive substance named *uranium Z*, and isotopic with protoactinium, accompanies uranium in minute quantity.[2] Its period is from 6 to 7 hours. It emits a β-radiation for which D_{AI} varies from 0.0014 to 0.012. Its parent is an isotope of thorium, but it cannot yet be placed in the series.

Note 10.—*Actinon* is also called the actinium emanation.

Note 11.—*Actinium C.* Two-tenths per cent. of the α-rays emitted by this substance have a range $a_0 = 6.10$, instead of 5.12. From this it has been concluded that 0.2% of the atoms undergo a transformation by the emission of β-rays as is the case in the radium C and thorium C branches.[3] Confirmatory evidence appears to be desirable.

Note 12.—*Actinium C″* is also called actinium D.

Note 13.—*Thorium.* The value given for λ is that obtained from the direct counting of the α-particles emitted by a compound of thorium. All the other values are less, the smallest being 0.55 of that given in the table and giving $\theta = 3.45 \times 10^{10}$ years, and $T = 2.37 \times 10^{11}$ years.[4]

Note 14.—*Thoron* is also called the thorium emanation.

Note 15.—*Thorium C* undergoes a double disintegration; 65% of the atoms emit β-rays and produce the substance ThC′ which gives α-rays, and 35% emit α-rays and produce the substance ThC″ which gives β-rays.

Note 16.—*Thorium C.* The value $a_0 = 4.69$ is that corresponding with $V = 0.0572$ which has been directly measured.

Note 17.—*Thorium C″* is also called thorium D.

Note 18.—*Potassium* and *rubidium* emit β-rays but give no other evidence of radioactivity.

Explanation of the Symbols

λ $(sec)^{-1}$ is the radioactive constant of the equations of transformation,

$$dQ = -\lambda Q dt, \qquad Q = Q_0 e^{-\lambda t}, \qquad \log_{10} \frac{Q_0}{Q} = 0.4343 \lambda t$$

[2] *Ber.*, **54B**, 1131 (1921).

[3] *Phil. Mag.*, [VI] **27**, 690; **28**, 818 (1914).

[4] *Physik. Z.*, **19**, 259 (1918).

INTERNATIONAL TABLE OF THE RADIOACTIVE ELEMENTS AND THEIR CONSTANTS, 1923

T	$\theta = \frac{1}{\lambda}$	λ (sec.)$^{-1}$	Name	Symbol	Atomic WT.	Atomic NO.	Isotope	Radiation	a_0	V	$\mu\beta$ Al	$\mu\gamma$ Al	$\mu\gamma$ Pb	Notes
SERIES of URANIUM and RADIUM														
4.67×10^9 years	6.75×10^9 years	4.7×10^{-18}	*Uranium I*	UI	238	92	U	α	2.37	0.0456	.....	.....	....	1
24.6 days	35.5 days	3.26×10^{-7}	*Uranium* X_1	UX_1	234	90	Th	β	....	.....	463	.....	....	...
1.15 minutes	1.65 minutes	0.010	*Uranium* X_2	UX_2	234	91	Pa	β (γ)	....	.....	14.4	24; 0.7; 0.14	0.72	2
2×10^6 years	3×10^6 years	10^{-14} (?)	*Uranium II*	UII	234	92	U	α	2.75	0.0479	.....	.....	....	...
6.9×10^4 years	10^5 years	3.2×10^{-13}	*Ionium*	Io	230	90	Th	α	2.85	0.0485	.....	.....	....	...
1690 years	2440 years	1.30×10^{-11}	*Radium*	Ra	226	88	Ra	α ($\beta+\gamma$)	3.13	α 0.0500; β 0.52; 0.65	312	354; 16; 0.27	....	...
3.85 days	5.55 days	2.085×10^{-6}	*Radon*	Rn	222	86	Rn	α	3.94	0.0540	.....	.....	....	3
3.0 minutes	4.32 minutes	3.85×10^{-3}	*Radium A*	RaA	218	84	Po	α	4.50	0.0565	.....	.....	....	...
26.8 minutes	38.7 minutes	4.30×10^{-4}	*Radium B*	RaB	214	82	Pb	β (γ)	....	0.36; 0.41; 0.63; 0.70; 0.74	13.1; 80	230; 40; 0.51	....	...
19.5 minutes	28.1 minutes	5.92×10^{-4}	*Radium C*	RaC	214	83	Bi	99.97% β and γ	....	0.786; 0.862; 0.949; 0.957	13.2; 53	0.115	0.50	4
10^{-6} second	10^{-6} second	10^6 (?)	*Radium C'*	RaC'	214	84	Po	α	6.57	0.0641	.....	.....	....	...
16.5 years	23.8 years	1.33×10^{-9}	*Radium D*	RaD	210	82	Pb	(β and γ)	....	0.33; 0.39	5500	45; 0.99	....	5
5.0 days	7.2 days	1.61×10^{-6}	*Radium E*	RaE	210	83	Bi	β	....	.....	43.3	.....	....	...
136 days	196 days	5.90×10^{-8}	*Radium F*[a]	RaF	210	84	Po	α (γ)	3.58	0.0523	.....	585	....	...
.....	.....	.....	*Radium* Ω[b]	Ra Ω'	206	82	Pb	.....	....	.....	.....	.....	....	...
.....	.....	[1.8×10^{-7}]	*Radium C*	RaC	214	83	Bi	0.03% α	?	.....	.....	.....	....	...
1.4 minutes	2.0 minutes	8.3×10^{-3}	*Radium C''*	RaC''	210	81	Tl	β	....	.....	.....	.....	....	6
.....	.....		*Radium* Ω''[c]	Ra Ω''	210	82	Pb	.....	....	.....	.....	.....	....	...
SERIES of ACTINIUM														
.....	.....	.....	*Uranium ?*	.....	?	92	U	α	....	.....	.....	.....	...	7
1.04 days	1.5 days	7.8×10^{-6}	*Uranium Y*	UY	?	90	Th	β	....	.....	About 300	.....	...	...
1.2×10^5 years	1.7×10^5 years	1.9×10^{-12}	*Protoactinium*	Pa	?	91	Pa	α	3.314	0.0510	.....	.....	...	8,9
20 years	28.8 years	1.1×10^{-9}	*Actinium*	Ac	?	89	Ac	—	....	.....	.....	.....	...	...
19.5 days	28.1 days	4.11×10^{-7}	*Radioactinium*	RdAc	?	90	Th	α (β)	4.36	α 0.0559; β 0.38; 0.43; 0.49 0.53; 0.60; 0.67; 0.73	About 170	25; 0.19	...	...
11.4 days	16.4 days	7.06×10^{-7}	*Actinium X*	AcX	?	88	Ra	α	4.17	0.0550	.....	.....	...	...
3.9 seconds	5.6 seconds	0.178	*Actinon*	An	?	86	Rn	α	5.40	0.0600	.....	.....	...	10

2.0×10^{-3} second	2.9×10^{-3} second	345	*Actinium A*	AcA	?	84	Po	α	6.16	0.0627	.....	.....	...	...
36.1 minutes	52.1 minutes	3.2×10^{-4}	*Actinium B*	AcB	?	82	Pb	(β and γ)	....	.....	Very large	120; 31; 0.45	...	11
2.15 minutes	3.10 minutes	5.37×10^{-3}	*Actinium C*	AcC	?	83	Bi	α	5.12	0.0589	.....	.....	...	...
4.71 minutes	6.83 minutes	2.44×10^{-3}	*Actinium C''*	AcC''	?	81	Tl	β and γ	....	.....	28.5	0 198	1.2 to 1.8	12
.....	.....	.....	*Actinium Ω''*[c]	Ac Ω''	?	82	Pb	.....	....	.....	.....	.....	...	...
			SERIES of THORIUM											
1.31×10^{10} years	1.89×10^{10} years	1.68×10^{-18}	*Thorium*	Th	232	90	Th	α	2.58	0.0469	.....	.....	...	13
6.7 years	9.67 years	3.28×10^{-9}	*Mesothorium 1*	MsTh1	228	88	Ra	—	....	.....	.....	.....	....	..
6.2 hours	8.9 hours	3.12×10^{-5}	*Mesothorium 2*	MsTh2	228	89	Ac	β and γ	....	0.37; 0.39; 0.43; 0.50; 0.57; 0.60; 0.66 and >0.70	20.2 to 38.5	26; 0.116	0.62	..
2.02 years	2.91 years	1.09×10^{-8}	*Radiothorium*	RdTh	228	90	Th	α (β)	3.67	α 0.0527; β 0.47; 0.51	.....	.....	....	..
3.64 days	5.25 days	2.20×10^{-6}	*Thorium X*	ThX	224	88	Ra	α	4.08	0.0546	.....	.....	....	..
54 seconds	78 seconds	0.0128	*Thoron*	Tn	220	86	Rn	α	4.74	0.0574	.....	.....	....	14
0.14 second	0.20 second	.5 0	*Thorium A*	ThA	216	84	Po	α	5.40	0.0600	.....	.....	....	..
10.6 hours	15.3 hours	1.82×10^{-5}	*Thorium B*	ThB	212	82	Pb	β and γ	....	0.63; 0.72	110	160; 32; 0.36	....	..
60 minutes	87 minutes	1.92×10^{-4}	*Thorium C*	ThC	212	83	Bi	65 % β	....	(C+C')0.29; 0.36; 0.93 to 0.95	14.4	.....	....	15
10^{-11} second	10^{-11} second	10^{11} (?)	*Thorium C'*	ThC'	212	84	Po	α	8.16	0.0688	.....	.....	....	..
.....	.....	.....	*Thorium Ω'*[b]	Th Ω'	208	82	Pb	.....	....	.....	.....	.....	....	..
.....	.....	[6.7×10^{-5}]	*Thorium C*	ThC	212	83	Bi	35 % α	4.55 ?4.69	0.0572	.....	.....	....	16
3.1 minutes	4 5 minutes	3.70×10^{-3}	*Thorium C''*	ThC''	208	81	Tl	β and γ	....	(See ThC)	21.6	0.096	0.46	17
.....	.....	.....	*Thorium Ω''*[b]	Th Ω''	208	82	Pb	.....	....	.....	.....	.....	....	..
.....	.....	.....	*Potassium*	K	39.1	19	K	β	....	.....	22 to 38	.....	....	18
.....	.....	.....	*Rubidium*	Rb	85.5	37	Rb	β	....	.....	308 to 347	.....	....	

[a] Polonium.
[b] Lead.
[c] Hypothetical.
[d] [1.25×10^{-4}].

in which Q_0 is the initial quantity and Q the quantity remaining after a time t (seconds).

$\lambda = -\frac{dQ}{Q}\frac{1}{dt}$ represents the fraction of the element transformed, reduced to the unit of time.

In the case of a double transformation, the values between brackets [ ] refer to the constants corresponding with the separate branches, the constant for both branches not being put between brackets.

The sign (?) indicates that the value has been indirectly deduced from the range of the α-rays expelled.

$\theta = \frac{1}{\lambda}$ is the average life of the radioactive atoms.

T is the period, that is, the time in which the quantity of radio element is diminished to one half.

$$\lambda T = -\log_e 0.5 = 0.69315 \text{ and } \theta = 1.443\ T$$

Radiation.—The parentheses () indicate that the radiation is relatively feeble.

a_0 is the range in centimeters of the α-rays in air at 0° and a pressure of 760 mm. of mercury.

The range at τ° and under p mm. of mercury is

$$a = \frac{a_0(273 + \tau)760}{273\ p}$$

V is the velocity of α- or β-rays relative to that of light.

To convert to cm./sec. multiply by 3×10^{10}.

For the α-rays, $V = 0.0342\ a^{1/2}$.

$\mu_{\beta Al}$ is the absorption coefficient of the β-rays in aluminum, the thickness being measured in cm.

$\mu_{\gamma Al}$ and $\mu_{\gamma Pb}$ are the absorption coefficients of the γ-rays in aluminum and lead, respectively, the thickness being measured in cm.; the latter is given for only the most penetrating type of γ-rays.

If I_0 is the initial intensity and I the intensity after the rays have traversed x cm. of the absorbent, $I = I_0\, e^{-\mu x}$; $\log_{10} \frac{I_0}{I} = 0.4343\ \mu x$.

If D is the thickness corresponding with the absorption of $^1/_2$ of the rays, $\mu D = 0.693$.

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THE SPECIFIC HEATS OF POLYATOMIC GASES AT LOW TEMPERATURES

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Received June 26, 1922

The specific heats of monatomic gases obey the equipartition law over a wide range of temperature[1] if we assume that the molecules have only translational energy. Even at high temperatures the specific heats of diatomic gases do not reach the value predicted by the equipartition law for all temperatures, and the experimental values decrease at first slowly, and then more rapidly, with decreasing temperature. Thus Eucken[2]

[1] Pier, *Z. Elektrochem.*, **15**, 536 (1909).

[2] Eucken, *Ber. Berl. Akad.*, **1912**, p. 141.