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INTERNATIONAL UNION OF PURE
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INORGANIC CHEMISTRY DIVISION

COMMISSION ON ATOMIC WEIGHTS AND
ISOTOPIC ABUNDANCES*

ATOMIC WEIGHTS OF THE ELEMENTS 1987

*Membership of the Commission for the period 1985–1987 was as follows:

R. L. Martin (Australia, Chairman); J. R. De Laeter (Australia, Secretary); R. C. Barber (Canada, Titular); I. L. Barnes (USA, Associate); J. Cesario (France, Associate); T. L. Chang (Beijing, China, Titular); T. B. Coplen (USA, Associate); J. W. Gramlich (USA, Associate); K. G. Heumann (FRG, Titular); N. E. Holden (USA, Associate); H. R. Krouse (Canada, Associate); I. A. Lebedev (USSR, Associate); T. J. Murphy (USA, Titular); K. J. R. Rosman (Australia, Associate); M. Shima (Japan, Titular); P. De Bièvre (Belgium, National Representative); N. N. Greenwood (UK, National Representative); H. S. Peiser (USA, National Representative).

Atomic weights of the elements 1987

Abstract - The biennial review of atomic weight $A_r(E)$ determinations and other cognate data has resulted in only one change from the 1985 values; namely, $A_r(E)$ for gallium is changed from 69.723 ± 0.004 to 69.723 ± 0.001. Attention is drawn to new isotopic abundance determinations of boron which indicate a real variation in commercial sources which at this time can be accommodated within the existing uncertainty of the standard atomic weight. The Table of Isotopic Compositions of the Elements will not be published as part of this biennial report but a revised table is in course of preparation. Current data on isotopic compositions of non-terrestrial materials are included together with a description of continuing work on natural isotopic fractionation which occurs for some elements. A review of the Tables of Atomic Weights both to Four and Five Significant figures is being undertaken.

INTRODUCTION

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Professor R L Martin from 22nd-25th August 1987, during the XXXIV IUPAC General Assembly in Boston, Massachusetts, United States of America. It was decided not to publish a 1987 Table of Isotopic Compositions of the Elements as Determined by Mass Spectrometry. Thus only the Report on the Atomic Weights of the Elements 1987 is presented here.

The Commission has monitored the literature over the past two years and evaluated the published data on atomic weights and isotopic compositions on an element-by-element basis. The atomic weight of an element can be determined from a knowledge of the isotopic abundances and corresponding atomic masses of the nuclides of that element. The latest compilation of the atomic masses was published in 1985 (Ref.1) which resulted in a number of small changes in the atomic weights that were reported in the 1985 Table (Ref.2).

The Commission now utilises the full range of uncertainties between ± 1 and ± 9 and following the acceptance of a set of Technical Guidelines at the Lyon meeting, a number of small but significant changes to the atomic weights was made (Ref.2). The Technical Guidelines have now been incorporated in a brochure which sets out the procedures and practices followed by the Commission. However it is emphasised that the collective judgement and experience of the Commission members is its most valuable asset which must be applied in each case.

COMMENTS ON SOME ATOMIC WEIGHTS

Boron - The Commission has been aware that boron from sea water is enriched by approximately 4% in the heavier isotope when compared with the terrestrial reference material NBS 951, but because sea water boron is unlikely to become a source of commercial boron, no change in the standard $A_r(B)$ or its uncertainty $U_r(B)$ was made. However the annotation "g" was added in 1985 (Ref.2) to indicate the presence of known sources of boron whose atomic weight is anomalous.

Recent precise measurements of the isotopic composition of boron (Refs.3-6) have confirmed that the $^{11}B/^{10}B$ ratio in marine and non-marine evaporites may be up to 3% higher or lower compared with the terrestrial reference material NBS 951 because of fractionation. It is quite likely that evaporite materials will become part of the source of boron for commercial and industrial purposes. The ± 3% variation in the $^{11}B/^{10}B$ ratio lies within the present uncertainty of ± 0.005 in the atomic weight of boron so that no change in the atomic weight or its uncertainty is required at this time. However the Commission wishes to draw attention to the emerging situation with respect to boron and will continue to monitor future isotopic measurements of this element.

Oxygen - The Commission noted that the $^{18}O/^{16}O$ ratios obtained from calibrated measurements of oxygen in air and in water are inconsistent. This fact casts doubt on all $^{17}O/^{16}O$ ratio measurements which are related to $^{18}O/^{16}O$ in air. It is strongly recommended that measurements of oxygen in air be repeated and that a calibrated measurement of $^{17}O/^{16}O$ in Vienna-Standard Mean Ocean Water (V-SMOW) be performed.

Gallium - In 1983 the Commission reviewed the published data for gallium (Ref.7) and decided to recommend an atomic weight of A_r(Ga) = 69.723(4), based on the calibrated mass spectrometric determination of De Laeter and Rosman (Ref.8), which was in good agreement with previous chemical and mass spectrometric measurements. The Commission discounted a coulometric assay of gallium (Ref.9), which was not in agreement with previous atomic weight determinations.

In 1985 the Commission left the value and uncertainty of A_r(Ga) unchanged (Ref.2) pending the outcome of a new calibrated mass spectrometric measurement then in progress. The Commission has now reviewed the calibrated mass spectrometric data of Machlan et al.(Ref.10) who reported A_r(Ga) = 69.72307(13). This value is in excellent agreement with the previous mass spectrometric measurement of De Laeter and Rosman (Ref.8), confirming the existing recommended value and allowing the uncertainty in A_r(Ga) to be decreased. The limiting factor in the uncertainty was based on the work of Gramlich and Machlan Ref.11) which showed significant isotopic variations in commercial high-purity gallium from different lots of material and different manufacturers. However no isotopic variations from natural sources have been observed. Based on this information the Commission has recommended A_r(Ga) = 69.723(1).

Mononuclidic Elements - An element is considered by the Commission to be mononuclidic if it has one and only one nuclide that is either stable or has a half-life greater than 3 x 10^{10}a. The upper limit of this half-life bound is set by elements with two nuclides in natural terrestrial sources one of which is radioactive with a half-life long enough to have survived since the earth was formed, notably $^{176}_{71}$Lu (3.6 x 10^{10}a), $^{187}_{75}$Re (4.1 x 10^{10}a), and $^{87}_{37}$Rb (4.9 x 10^{10}a). At the other extreme there are elements with one stable nuclide and a second radioactive nuclide with a half-life too short to have survived in measurable quantities since the earth formed. Its terrestrial occurrence is therefore limited to radiogenic, cosmic ray, or synthetic nuclear processes. These relevant nuclides notably include $^{92}_{41}$Nb (3.7 x 10^{7}a) and $^{129}_{53}$I (1.6 x 10^{7}a).

From these two considerations alone there remains a range in half-life of three orders of magnitude as demarcation between the two kinds of radioactive nuclides. However, there are two more considerations that restrict the choice. If the demarcation were placed between 7.0 x 10^{8}a (the half-life of $^{235}_{92}$U), and 4.5 x 10^{9}a (the half-life of $^{238}_{92}$U), uranium would become a mononuclidic element. The arbitrary boundary should therefore be outside the range between these two uranium half-lives.

The final choice of criterion concerns the question of whether any radioactive element should be considered mononuclidic. The only such element which has (on occasions) in the past and would thus in future be so designated by the Commission is thorium if the demarcation were set below 1.4 x 10^{10}a, the half-life of $^{232}_{90}$Th. This designation would be undesirable because of its varying contamination with significant amounts of the radiogenic nuclide $^{230}_{90}$Th.

Therefore by setting a demarcation in half-life of 3 x 10^{10}a, the Commission considers only the following twenty elements to be mononuclidic:

Be, F, Na, Al, P, Sc, Mn, Co, As, Y, Nb, Rh, I, Cs, Pr, Tb, Ho, Tm, Au, and Bi.

Using this criterion, protactinium is excluded.

THE TABLE OF STANDARD ATOMIC WEIGHTS 1987

Following past practice the 1987 Table of Standard Atomic Weights is presented both in alphabetical order by English names of the elements (Table 1) and in the order of atomic number (Table 2).

The names and symbols for those elements with atomic numbers 104 to 107 referred to in the following tables are systematic and based on the atomic numbers of the elements as recommended by the IUPAC Commission of the Nomenclature of Inorganic Chemistry (Ref.12). The names are composed of the following roots representing digits of the atomic number:

1 un, 2 bi, 3 tri, 4 quad, 5 pent,
6 hex, 7 sept, 8 oct, 9 enn, 10 nil.

The ending "ium" is then added to these three roots. The three-letter symbols are derived from the first letters of the corresponding roots.

The Commission again wishes to emphasise the need for new precise isotopic composition measurements in order to improve the accuracy of the atomic weight of a number of elements which are still not known to the desired level of accuracy.

TABLE 1. Standard Atomic Weights 1987

(Scaled to $\underline{A}_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $\underline{A}_r(E)$ and uncertainty $\underline{U}_r(E)$ given here apply to elements as they exist naturally on earth.

Alphabetical order in English

Name	Symbol	Atomic Number	Atomic Weight	Footnotes			
Actinium*	Ac	89					A
Aluminium	Al	13	26.981539(5)				
Americium*	Am	95					A
Antimony (Stibium)	Sb	51	121.75(3)				
Argon	Ar	18	39.948(1)	g		r	
Arsenic	As	33	74.92159(2)				
Astatine*	At	85					A
Barium	Ba	56	137.327(7)				
Berkelium*	Bk	97					A
Beryllium	Be	4	9.012182(3)				
Bismuth	Bi	83	208.98037(3)				
Boron	B	5	10.811(5)	g	m	r	
Bromine	Br	35	79.904(1)				
Cadmium	Cd	48	112.411(8)	g			
Caesium	Cs	55	132.90543(5)				
Calcium	Ca	20	40.078(4)	g			
Californium*	Cf	98					A
Carbon	C	6	12.011(1)			r	
Cerium	Ce	58	140.115(4)	g			
Chlorine	Cl	17	35.4527(9)				
Chromium	Cr	24	51.9961(6)				
Cobalt	Co	27	58.93320(1)				
Copper	Cu	29	63.546(3)			r	
Curium*	Cm	96					A
Dysprosium	Dy	66	162.50(3)	g			
Einsteinium*	Es	99					A
Erbium	Er	68	167.26(3)	g			
Europium	Eu	63	151.965(9)	g			
Fermium*	Fm	100					A
Fluorine	F	9	18.9984032(9)				
Francium*	Fr	87					A
Gadolinium	Gd	64	157.25(3)	g			
Gallium	Ga	31	69.723(1)				
Germanium	Ge	32	72.61(2)				
Gold	Au	79	196.96654(3)				
Hafnium	Hf	72	178.49(2)				
Helium	He	2	4.002602(2)	g		r	
Holmium	Ho	67	164.93032(3)				
Hydrogen	H	1	1.00794(7)	g	m	r	
Indium	In	49	114.82(1)				
Iodine	I	53	126.90447(3)				
Iridium	Ir	77	192.22(3)				
Iron	Fe	26	55.847(3)				
Krypton	Kr	36	83.80(1)	g	m		
Lanthanum	La	57	138.9055(2)	g			
Lawrencium*	Lr	103					A
Lead	Pb	82	207.2(1)	g		r	
Lithium	Li	3	6.941(2)	g	m	r	
Lutetium	Lu	71	174.967(1)	g			
Magnesium	Mg	12	24.3050(6)				
Manganese	Mn	25	54.93805(1)				
Mendelevium*	Md	101					A
Mercury	Hg	80	200.59(3)				
Molybdenum	Mo	42	95.94(1)				
Neodymium	Nd	60	144.24(3)	g			
Neon	Ne	10	20.1797(6)	g	m		
Neptunium*	Np	93					A

TABLE 1. Standard Atomic Weights 1987 (contd)

Name	Symbol	Atomic Number	Atomic Weight	Footnotes			
Nickel	Ni	28	58.69(1)				
Niobium	Nb	41	92.90638(2)				
Nitrogen	N	7	14.00674(7)	g		r	
Nobelium*	No	102					A
Osmium	Os	76	190.2(1)	g			
Oxygen	O	8	15.9994(3)	g		r	
Palladium	Pd	46	106.42(1)	g			
Phosphorus	P	15	30.973762(4)				
Platinum	Pt	78	195.08(3)				
Plutonium*	Pu	94					A
Polonium*	Po	84					A
Potassium(Kalium)	K	19	39.0983(1)				
Praseodymium	Pr	59	140.90765(3)				
Promethium*	Pm	61					A
Protactinium*	Pa	91					
Radium*	Ra	88					A
Radon*	Rn	86					A
Rhenium	Re	75	186.207(1)				
Rhodium	Rh	45	102.90550(3)				
Rubidium	Rb	37	85.4678(3)	g			
Ruthenium	Ru	44	101.07(2)	g			
Samarium	Sm	62	150.36(3)	g			
Scandium	Sc	21	44.955910(9)				
Selenium	Se	34	78.96(3)				
Silicon	Si	14	28.0855(3)			r	
Silver	Ag	47	107.8682(2)	g			
Sodium(Natrium)	Na	11	22.989768(6)				
Strontium	Sr	38	87.62(1)	g		r	
Sulfur	S	16	32.066(6)			r	
Tantalum	Ta	73	180.9479(1)				
Technetium*	Tc	43					A
Tellurium	Te	52	127.60(3)	g			
Terbium	Tb	65	158.92534(3)				
Thallium	Tl	81	204.3833(2)				
Thorium*	Th	90	232.0381(1)	g			Z
Thulium	Tm	69	168.93421(3)				
Tin	Sn	50	118.710(7)	g			
Titanium	Ti	22	47.88(3)				
Tungsten (Wolfram)	W	74	183.85(3)				
Unnilquadium	Unq	104					A
Unnilpentium	Unp	105					A
Unnilhexium	Unh	106					A
Unnilseptium	Uns	107					A
Uranium*	U	92	238.0289(1)	g	m		Z
Vanadium	V	23	50.9415(1)				
Xenon	Xe	54	131.29(2)	g	m		
Ytterbium	Yb	70	173.04(3)	g			
Yttrium	Y	39	88.90585(2)				
Zinc	Zn	30	65.39(2)				
Zirconium	Zr	40	91.224(2)	g			

g geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed the implied uncertainty.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. Substantial deviations in atomic weight of the element from that given in the Table can occur.

r range in isotopic composition of normal terrestrial material prevents a more precise $A_r(E)$ being given; the tabulated $A_r(E)$ value should be applicable to any normal material.

A Radioactive element that lacks a characteristic terrestrial isotopic composition. One or more well-known isotopes are given in Table 3 with the appropriate mass and half-life.

Z An element, without stable nuclide(s), exhibiting a range of characteristic terrestrial compositions of long-lived radionuclide(s) such that a meaningful atomic weight can be given.

* Element has no stable nuclides.

TABLE 2. Standard Atomic Weights 1987

(Scaled to $A_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ and uncertainty $U_r(E)$ given here apply to elements as they exist naturally on earth.

Order of Atomic Number

Atomic Number	Name	Symbol	Atomic Weight	Footnotes			
1	Hydrogen	H	1.00794(7)	g	m	r	
2	Helium	He	4.002602(2)	g		r	
3	Lithium	Li	6.941(2)	g	m	r	
4	Beryllium	Be	9.012182(3)				
5	Boron	B	10.811(5)	g	m	r	
6	Carbon	C	12.011(1)			r	
7	Nitrogen	N	14.00674(7)	g		r	
8	Oxygen	O	15.9994(3)	g		r	
9	Fluorine	F	18.9984032(9)				
10	Neon	Ne	20.1797(6)	g	m		
11	Sodium(Natrium)	Na	22.989768(6)				
12	Magnesium	Mg	24.3050(6)				
13	Aluminium	Al	26.981539(5)				
14	Silicon	Si	28.0855(3)			r	
15	Phosphorus	P	30.973762(4)				
16	Sulfur	S	32.066(6)			r	
17	Chlorine	Cl	35.4527(9)				
18	Argon	Ar	39.948(1)	g		r	
19	Potassium(Kalium)	K	39.0983(1)				
20	Calcium	Ca	40.078(4)	g			
21	Scandium	Sc	44.955910(9)				
22	Titanium	Ti	47.88(3)				
23	Vanadium	V	50.9415(1)				
24	Chromium	Cr	51.9961(6)				
25	Manganese	Mn	54.93805(1)				
26	Iron	Fe	55.847(3)				
27	Cobalt	Co	58.93320(1)				
28	Nickel	Ni	58.69(1)				
29	Copper	Cu	63.546(3)			r	
30	Zinc	Zn	65.39(2)				
31	Gallium	Ga	69.723(1)				
32	Germanium	Ge	72.61(2)				
33	Arsenic	As	74.92159(2)				
34	Selenium	Se	78.96(3)				
35	Bromine	Br	79.904(1)				
36	Krypton	Kr	83.80(1)	g	m		
37	Rubidium	Rb	85.4678(3)	g			
38	Strontium	Sr	87.62(1)	g		r	
39	Yttrium	Y	88.90585(2)				
40	Zirconium	Zr	91.224(2)	g			
41	Niobium	Nb	92.90638(2)				
42	Molybdenum	Mo	95.94(1)				
43	Technetium*	Tc					A
44	Ruthenium	Ru	101.07(2)	g			
45	Rhodium	Rh	102.90550(3)				
46	Palladium	Pd	106.42(1)	g			
47	Silver	Ag	107.8682(2)	g			
48	Cadmium	Cd	112.411(8)	g			
49	Indium	In	114.82(1)				
50	Tin	Sn	118.710(7)	g			
51	Antimony(Stibium)	Sb	121.75(3)				
52	Tellurium	Te	127.60(3)	g			
53	Iodine	I	126.90447(3)				
54	Xenon	Xe	131.29(2)	g	m		
55	Caesium	Cs	132.90543(5)				
56	Barium	Ba	137.327(7)				
57	Lanthanum	La	138.9055(2)	g			
58	Cerium	Ce	140.115(4)	g			

TABLE 2. Standard Atomic Weights 1987 (contd)

Atomic Number	Name	Symbol	Atomic Weight	Footnotes	
59	Praseodymium	Pr	140.90765(3)		
60	Neodymium	Nd	144.24(3)	g	
61	Promethium*	Pm			A
62	Samarium	Sm	150.36(3)	g	
63	Europium	Eu	151.965(9)	g	
64	Gadolinium	Gd	157.25(3)	g	
65	Terbium	Tb	158.92534(3)		
66	Dysprosium	Dy	162.50(3)	g	
67	Holmium	Ho	164.93032(3)		
68	Erbium	Er	167.26(3)	g	
69	Thulium	Tm	168.93421(3)		
70	Ytterbium	Yb	173.04(3)	g	
71	Lutetium	Lu	174.967(1)	g	
72	Hafnium	Hf	178.49(2)		
73	Tantalum	Ta	180.9479(1)		
74	Tungsten (Wolfram)	W	183.85(3)		
75	Rhenium	Re	186.207(1)		
76	Osmium	Os	190.2(1)	g	
77	Iridium	Ir	192.22(3)		
78	Platinum	Pt	195.08(3)		
79	Gold	Au	196.96654(3)		
80	Mercury	Hg	200.59(3)		
81	Thallium	Tl	204.3833(2)		
82	Lead	Pb	207.2(1)	g r	
83	Bismuth	Bi	208.98037(3)		
84	Polonium*	Po			A
85	Astatine*	At			A
86	Radon*	Rn			A
87	Francium*	Fr			A
88	Radium*	Ra			A
89	Actinium*	Ac			A
90	Thorium*	Th	232.0381(1)	g	Z
91	Protactinium*	Pa			
92	Uranium*	U	238.0289(1)	g m	Z
93	Neptunium*	Np			A
94	Plutonium*	Pu			A
95	Americium*	Am			A
96	Curium*	Cm			A
97	Berkelium*	Bk			A
98	Californium*	Cf			A
99	Einsteinium*	Es			A
100	Fermium*	Fm			A
101	Mendelevium*	Md			A
102	Nobelium*	No			A
103	Lawrencium*	Lr			A
104	Unnilquadium	Unq			A
105	Unnilpentium	Unp			A
106	Unnilhexium	Unh			A
107	Unnilseptium	Uns			A

g geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed the implied uncertainty.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. Substantial deviations in atomic weight of the element from that given in the Table can occur.

r range in isotopic composition of normal terrestrial material prevents a more precise $A_r(E)$ being given; the tabulated $A_r(E)$ value should be applicable to any normal material.

A Radioactive element that lacks a characteristic terrestrial isotopic composition. One or more well-known isotopes are given in Table 3 with the appropriate mass and half-life.

Z An element, without stable nuclide(s), exhibiting a range of characteristic terrestrial compositions of long-lived radionuclide(s) such that a meaningful atomic weight can be given.

*Element has no stable nuclides.

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

The Commission on Atomic Weights and Isotopic Abundances has, for many years, published a Table of Relative Atomic Masses and Half-Lives of Selected Radionuclides for elements without a stable nuclide. Since the Commission has no prime responsibility for the dissemination of such values, it has not attempted either to record the best precision possible or make its tabulation comprehensive. The radionuclides selected are those judged to be necessary to enable users to calculate the atomic weights of materials of abnormal isotopic composition. There is no general agreement on which of the isotopes of the radioactive elements is, or is likely to be judged, "important" and various criteria such as "longest half-life", "production in quantity", "used commercially", etc. will be apposite for different situations. The relative atomic masses are derived from the atomic masses (in u) recommended by Wapstra and Audi (Ref.1). The half-lives listed are those provided by Holden (Refs.13, 14).

TABLE 3. Relative Atomic Masses and Half-lives of Selected Radionuclides

Atomic Number	Element Name	Element Symbol	Mass No	Relative Atomic Mass	Half Life	Unit
43	Technetium	Tc	97	96.9064	2.6×10^6	a
			98	97.9072	4.2×10^6	a
			99	98.9063	2.1×10^5	a
61	Promethium	Pm	145	144.9127	18	a
			147	146.9151	2.62	a
84	Polonium	Po	209	208.9824	1×10^2	a
			210	209.9828	138	d
85	Astatine	At	210	209.9871	8	h
			211	210.9875	7.2	h
86	Radon	Rn	211	210.9906	15	h
			220	220.0114	56	s
			222	222.0176	3.82	d
87	Francium	Fr	223	223.0197	22	m
88	Radium	Ra	223	223.0185	11	d
			224	224.0202	3.7	d
			226	226.0254	1600	a
			228	228.0311	5.8	a
89	Actinium	Ac	227	227.0278	21.8	a
90	Thorium	Th	230	230.0331	7.54×10^4	a
			232	232.0381	1.40×10^{10}	a
91	Protactinium	Pa	231	231.0359	3.28×10^4	a
92	Uranium	U	233	233.0396	1.59×10^5	a
			234	234.0409	2.46×10^5	a
			235	235.0439	7.04×10^8	a
			236	236.0456	2.34×10^7	a
			238	238.0508	4.47×10^9	a
93	Neptunium	Np	237	237.0482	2.14×10^6	a
			239	239.0529	2.35	d
94	Plutonium	Pu	238	238.0496	87.7	a
			239	239.0522	2.41×10^4	a
			240	240.0538	6.56×10^3	a
			241	241.0568	14.4	a
			242	242.0587	3.74×10^5	a
			244	244.0642	8.0×10^7	a
95	Americium	Am	241	241.0568	432	a
			243	243.0614	7.37×10^3	a
96	Curium	Cm	243	243.0614	29	a
			244	244.0627	18.1	a
			245	245.0655	8.4×10^3	a
			246	246.0672	4.8×10^3	a
			247	247.0703	1.6×10^7	a
			248	248.0723	3.5×10^5	a
97	Berkelium	Bk	247	247.0703	1.4×10^3	a
			249	249.0750	3.3×10^2	d
98	Californium	Cf	249	249.0748	3.5×10^2	a
			250	250.0764	13.1	a
			251	251.0796	9.0×10^2	a
			252	252.0816	2.64	a

TABLE 3. Relative Atomic Masses and Half-lives of Selected Radionuclides (contd)

Atomic Number	Element Name	Element Symbol	Mass No	Relative Atomic Mass	Half Life	Unit
99	Einsteinium	Es	252	252.083	1.3	a
100	Fermium	Fm	257	257.0951	101	d
101	Mendelevium	Md	256	256.094	76	m
			258	258.10	55	d
102	Nobelium	No	259	259.1009	58	m
103	Lawrencium	Lr	262	262.11	216	m
104	Unnilquadium	Unq	261	261.11	65	s
105	Unnilpentium	Unp	262	262.114	34	s
106	Unnilhexium	Unh	263	263.118	0.9	s
107	Unnilseptium	Uns	262	262.12	0.12	s

a = years d = days h = hours m = minutes s = seconds

NON-TERRESTRIAL DATA

The isotopic abundances of elements from non-terrestrial sources form a rapidly expanding body of knowledge. Information about non-terrestrial isotopic abundances can be obtained from mass spectrometric studies of meteoritic, lunar and interplanetary dust materials, from space probes, from astronomical observations using infrared spectra, and from cosmic ray analysis.

It has been established that many elements have a different isotopic composition in non-terrestrial materials when compared with normal terrestrial materials. These effects have been demonstrated by precise mass spectrometric measurements of meteorites, lunar materials and interplanetary dust. Excellent reviews describing isotopic anomalies in non-terrestrial materials are given by Anders (Ref.15), Begemann (Ref.16), Clayton (Ref.17), Pillinger (Ref.18), Scott (Ref.19), Wasserburg et al (Ref.20), Geiss and Bochsler (Ref.21) and Wiedenbeck (Ref.22). Fowler (Ref.23) also touched on this problem in his Nobel lecture in Stockholm, Sweden.

It is important to realise that, although most of the reported isotopic anomalies are small, some variations are quite large. For this reason, scientists dealing with non-terrestrial samples should exercise caution when the isotopic composition or the atomic weight of a non-terrestrial sample is required,

The data have been classified according to the major alteration or production processes or the sources of material as described in the following outline:

Process

A. Mass Fractionation
Mass dependent fractionation has occurred both before and after the formation of the solar system.

A-1 Fractionation by volatization and condensation.

A-2 Fractionation by chemical processes: This grouping includes some special cases, such as the production of organic matter.

B. Nuclear Reactions

B-1 Nucleosynthesis: The mechanism of formation of some of these nucleosynthetic materials is open to question. Tabulated here are samples identified by the authors as products of nucleosynthesis.

B-2 Spallation Reactions: Nuclear reactions produced by galactic and solar cosmic ray bombardment prior to the fall of the meteorite.

B-3 Low Energy Thermal Neutron Capture Reactions: Bombardment of the lunar surface or meteorites by thermal neutrons originating from cosmic rays.

C. Radioactive Decay Products

C-1 Products from Extinct Nuclides: When the solar system had evolved to the point where the meteorites had become closed isotopic systems some 4.6 x 10^9 years ago, some radioactive nuclides, now extinct in the solar system, were still present. Daughter products of such nuclides are responsible for the anomalous isotopic composition of certain elements.

C-2 Enrichments in the Daughter Products of Radioactive Nuclides which are commonly used for Geochronology.
C-3 Enrichments as the result of the double ß-decay of long-lived radioactive nuclides.
C-4 Enrichments as the result of the decay of fission products.
C-5 Preferential Loss of Light Gases from the Gravitational field of the Object: For example, the helium and argon in the earth's atmosphere are presently composed of very little of the primoridal helium and argon gas but instead are composed of the outgassed helium and argon decay products from the heavy, naturally radioactive elements and from ^{40}K respectively.

Sources

a. Solar Particles
a-1 Solar Wind: Lunar samples and gas-rich chondrites have shown evidence of isotopic modification because of ancient and recent solar wind.
a-2 Solar Flare: During the solar event of September 23, 1978, a satellite borne "heavy isotope spectrometer telescope" (HIST) successfully measured isotopic ratios of several elements found in the energetic particle fluxes emitted by the sun.

b. Cosmic Rays
Data included in this category are the results of cosmic ray measurements in the near-earth environment by balloon and satellite experiments.
b-1 Relatively Low-Energy Cosmic Rays (20 to 1000 MeV/u): The recent development of high resolution detectors makes it possible to measure the relative isotopic abundance of several elements.
b-2 High-Energy Cosmic Rays (>6 GeV/u): Despite experimental difficulties, $^{3}He/^{4}He$ ratios have now been determined.

c. Cool Stars
Isotopic ratios of C and O in cool giant- and supergiant-stars and Mg in metal-poor subgiant stars have been obtained from their infrared spectra using large ground-based telescopes.

d. Planets and Satellites
Isotopic ratios of some elements in planets and one satellite of Saturn, (namely Titan), were determined by spacecraft-borne mass spectrometry and infrared spectrometry, and by ground-based infrared spectrometry.

e. Comet Halley
D/H and $^{18}O/^{16}O$ ratios in comet Halley were measured by the Giotto spacecraft-borne mass spectrometry on March 14, 1986. Preliminary results reported by Eberhardt et al (Ref.24) are as follows:

$0.6 \times 10^{-4} < D/H < 4.8 \times 10^{-4}$ (terrestrial value; 1.5×10^{-4})
$^{18}O/^{16}O = 0.0023 \pm 0.0006$ (terrestrial value; 0.00200).

f. Interplanetary Dust (Cosmic Dust)

Isotopic ratios of H, He, C, Ne, Mg and Si in so-called interplanetary dust and stratospheric dust have been determined.

Although this Commission does not attempt to systematically review the literature on the isotopic composition of non-terrestrial materials, some examples of isotopic variations have been given in past reports. In order to provide a more comprehensive view of current research on the isotopic variations found in non-terrestrial materials, we have chosen in this report to present some of these data in Tables 4 and 5.

Table 4 lists experimental results for a selection of the largest reported variations. This information has been classified in terms of the major process involved in the modification of the isotopic composition of the element concerned. Thus for example, the table lists, as one of the items, the largest deviation of isotopic composition reported for the isotopes of calcium caused by a mass fractionation process (A-1). Only data of enrichment or depletion of specific isotopes produced predominantly by one of the major alteration processes are listed. The data listed in Table 4 are limited to measured values reported in publications and in no instance represent interpolations or extrapolations. Those interested in a more comprehensive review should refer to Shima (Ref.25).

Entries given as "δ" or "/u" (per atomic mass unit) are all in per mil (per 1000). The δ values are expressed by respective mass numbers, for example, the meaning of δ(18,16) is as follows:

$$\delta(18,16) = \left[\frac{(^{18}O / ^{16}O)_s}{(^{18}O / ^{16}O)_n} - 1 \right] \times 1000$$

s: Non-terrestrial Sample
n: Terrestrial Standard

Where an isotopic ratio or atomic weight is given, the terrestrial value is listed in parenthesis for comparison, suitably truncated where necessary to an appropriate number of significant figures.

TABLE 4. Examples of Maximum Isotopic Variations and Corresponding Atomic Weights due to Different Processes

Element	Iostopic Ratio Maximum Variation	Atomic Weight	Materials	Process	Reference
$_7N$	δ(15,14); +190 (14.0067)	14.0074	C2-chondrite Renazzo	A-2	(26)
$_8O$	δ(17,16); -42.8 δ(18,16); -40.5	15.9991 (15.9994)	spinel from type B CAI HN-3 of C3-chondrite, Allende	B-1	(27)
$_{12}Mg$	$^{26}Mg/^{24}Mg$=0.703 (0.13938)		hibonite from C2-chondrite Murchison	C-1	(28)
$_{18}Ar$	$^{40}Ar/^{36}Ar=1.2\times10^{-3}$ (295.5)		1850°C release from Carbon-rich residue of ureilite Dyalpur	C-5	(29)
$_{20}Ca$	7.5 / u		HAL inclusion of C3-chondrite, Allende	A-1	(30)
$_{23}V$	$^{51}V/^{50}V$=4.3 (399)	50.76 (50.94)	iron meteorite Grant	B-2	(31)
$_{36}Kr$	$^{82}Kr/^{84}Kr$=0.355 (0.203)		1000°C release from FeS in iron meteorite Cape York	C-3	(32)
$_{38}Sr$	$^{87}Sr/^{86}Sr$=8.45 (0.7099)	87.31 (87.62)	silicate inclusion of iron meteorite Colomela	C-2	(33)
$_{54}Xe$	$^{136}Xe/^{132}Xe$=0.617 (0.331)		600°C release from <2.89g/cm^3 density fraction of C3-chondrite Allende	C-4	(34)
$_{64}Gd$	δ(158,157);+5.97		lunar rock, 10017,56	B-3	(35)

Table 5 lists examples of the isotopic compositions and atomic weights of elements from different sources.

TABLE 5. Examples of Isotopic Composition and Atomic Weight from Different Sources

Element	Object	Isotopic Ratio	Atomic Weight	Method	Source	Reference
^{1}H	Venus	2/1; 0.022	1.029	Pioneer Venus orbiter IMS	d	(36)
	Jupiter	3.6×10^{-5}	1.0079	Voyager IRIS	d	(37)
	Saturn	1.6×10^{-5}	1.0078	Voyager IRIS	d	(38)
	Titan	4.2×10^{-4}	1.0082	Voyager IRIS	d	(39)
	Earth	1.50×10^{-4}	1.00794			
^{4}He	Solar wind	3/4; 4.8×10^{-4}	4.0021	Spacecraft ISEE-3 borne IMS	a-1	(40)
	Solar flare	0.0026	4.0000	Spacecraft ISEE-3 borne HIST	a-2	(41)
	Cosmic ray 48 - 77 MeV/u	0.066	3.94	Spacecraft ISEE-3 borne HIST	b-1	(42)
	>6GeV/u	0.24	3.81	Balloon-borne detector	b-2	(43)
	Interplanetary dust	0.023	3.98	(1600°C release, Pacific deep-sea magnetic fine sample). MS	f	(44)
	Earth	1.380×10^{-6}	4.002602			
^{6}C	most of Cool star	12/13; 3.4-35	12.23 - 12.03	Infrared spectra by large ground-based telescope	c	(45)
	Venus	≥ 84	≤ 12.01	Pioneer Venus LNMS	d	(46)
	Mars	83.3	12.012	Viking lander Mars' surface NMS	d	(47)
	Jupiter	160	12.006	Voyager IRIS	d	(48)
	Stratospheric dust	94.6	12.010	(collected at >60,000 ft. with an aircraft).SIMS	f	(49)
	Earth	89.91	12.011			

IMS: Ion Mass Spectrometer
IRIS: Infrared Interferometer Spectrometer
HIST: Heavy Isotope Spectrometer Telescope
LNMS: Large Probe Neutral Mass Spectrometer
NMS: Neutron Mass Spectrometer
MS: Mass Spectrometer
SIMS: Secondary Ion Mass Spectrometer

OTHER PROJECTS OF THE COMMISSION

The Editor of "Chemistry International" has requested the Commission's permission to reprint the Table of Atomic Weights to Four Significant Figures. Members of the Commission will provide an updated version of the Table for this purpose.

The Commission has also decided to revise and republish the Table of Atomic Weights to Five Significant Figures. A Working Party has been formed to undertake this task by the time of the next meeting of the General Assembly in 1989.

The Commission strongly supported a new interdivisional project entitled "Isotope Specific Measurements as Reference Techniques for Toxic/Essential Element Assay" after receiving a report from Professor P De Bièvre who was co-opted by the Division to liaise with the Clinical Chemistry Division of IUPAC. Professor De Bièvre expressed the opinion that much of the required expertise for this project resides in the Commission and that the project should be attached to the Inorganic Chemistry Division.

The Commission initiated three new projects at the Lyon meeting in 1985 and the work is described below:-

A Sub-Committee for Isotopic Abundance Measurements (SIAM) was established to identify and assess experimental methods leading to isotope abundances/atomic masses/atomic weights, and to critically evaluate any new data pertaining to the work of the Commission. The Sub-Committee has surveyed critically the isotopic abundance data determined by mass spectrometry which have been published over the past two years and plans to publish a revised Table of Isotopic Compositions of the Elements after the next General Assembly. This Table was last published in 1984 (Ref.50). The Table is continually maintained and a current copy can be obtained from the Convenor of SIAM, Dr I L Barnes of the National Bureau of Standards, Gaithersburg, Maryland, 20899, USA.

The Commission's working party on Natural Isotopic Fractionation, was formed to investigate the impact of naturally occurring fractionation processes upon (1) determination of the atomic weight of that element, (2) determination of the uncertainty in its atomic weight and (3) determination of the isotopic composition of an element. The working party agreed that its primary role is to prepare a comprehensive tabulation of isotopic fractionation factors for all elements that show isotopic fractionation in naturally occurring terrestrial materials and whose fractionation factors have been experimentally or theoretically determined. It is expected that this compilation would be a significant expansion of the 1975 "Data of Geochemistry, compilation of Stable Isotope Fractionation Factors of Geochemical Interest" (Ref.51) which currently serves as the accepted source for isotopic fractionation factors in light stable isotope geochemistry. Whereas the compilation of Friedman and O'Neil included only isotopic fractionation factors of hydrogen, carbon, oxygen, and sulphur, it was proposed that the working party should consider the following elements: hydrogen, lithium, boron, carbon, nitrogen, oxygen, neon, magnesium, silicon, sulphur, chlorine, potassium, calcium, iron, copper, selenium, palladium, tellurium, mercury, and uranium.

Furthermore, the compilation would recommend a "best" isotopic fractionation factor where more than one was available. The working party agreed that it will not investigate non mass-dependent isotopic effects because these are not important in the isotopic fractionation of terrestrial materials. The working party will prepare a draft of this compilation for distribution to the Commission at the 1989 General Assembly.

The working party on Measurements, Sensors and Measuring Instruments has produced a short annotated bibliography for students on uncertainties in measurements. Foreign language versions will be made available in Chinese, French, German, Japanese and Russian, when the bibliography is finalised. The working party will prepare a draft document on realistic evaluation of uncertainties in chemical measurements before the next General Assembly in 1989.

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