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Atomic weights of the elements 2007 (IUPAC Technical Report)*

Michael E. Wieser[1,‡] and Michael Berglund[2]

[1]Department of Physics and Astronomy, University of Calgary, Canada; [2]European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM), Belgium

Abstract: The latest evaluation of atomic weight determinations and other cognate data has warranted five changes for the standard atomic weights of the elements, A_r(E), from those published previously in the Table of Atomic Weights 2005. The revised standard atomic weight of nickel, A_r(Ni), is 58.6934(4); zinc, A_r(Zn), is 65.38(2); molybdenum, A_r(Mo), is 95.96(2); ytterbium, A_r(Yb), is 173.054(5); and lutetium, A_r(Lu), is 174.966 8(1). Standard atomic weight tables abridged to four and five significant figures were also evaluated. The Commission-recommended value for the isotope-amount ratio of $n(^{40}\mathrm{Ar})/n(^{36}\mathrm{Ar})$, which is of importance in geochronology and geochemistry, has been changed to 298.56(31) from 296.03(53) based on new measurements. Atmospheric O_2 is recognized as an international measurement standard, along with Vienna Standard Mean Ocean Water (VSMOW) and Vienna Pee Dee Belemnite (VPDB) carbonate for measurement and reporting of differences in relative oxygen isotope-amount ratios $\delta(^{17}\mathrm{O})$ and $\delta(^{18}\mathrm{O})$.

Keywords: argon isotopes; half-lives; IUPAC Inorganic Chemistry Division; lutetium; molybdenum; nickel; oxygen-17; ytterbium; zinc.

INTRODUCTION

The Commission on Isotopic Abundances and Atomic Weights (CIAAW) met in Pisa, Italy under the chairmanship of Prof. T. P. Ding from 30 to 31 July 2007, prior to the 44th IUPAC General Assembly in Torino, Italy. The Commission decided to publish the report "Atomic Weights of the Elements 2007" as presented here. The resulting Table of Standard Atomic Weights is given in alphabetical order of the principal English names in Table 1 and in order of atomic number in Table 2. The standard atomic weights reported in Tables 1 and 2 are for atoms in their nuclear and electronic ground states.

At the 2007 meeting, the Commission reviewed recommendations of its Subcommittee on Isotopic Abundance Measurements (SIAM), which reviewed the literature from the past two years since the most recent published version of atomic weights [1,2]. The last complete compilation of isotopic compositions on an element-by-element basis was done in 2001 [3]. The SIAM data evaluation meeting was led under the chairmanship of Dr. M. Berglund.

The Commission periodically reviews the history of the standard atomic weight of each element, emphasizing the relevant published scientific evidence on which decisions have been made [4,5]. The Commission wishes to emphasize the need for new precise calibrated isotope composition measure-

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‡Corresponding author: mwieser@ucalgary.ca

ments in order to improve the standard atomic weights of a number of elements, which are still not known to a satisfactory level of accuracy. However, for many elements, the uncertainties of the standard atomic weights are limited by the variability among terrestrial materials rather than by the accuracy or precision of the measurements.

The atomic weight, A_r(E), of element E in a given substance can be determined from the knowledge of the isotopic abundances and corresponding atomic masses of the nuclides of that element. The Commission used the atomic mass evaluations of 2003 [6] for calculations of the atomic weights that were changed in this compilation. Depending on the element in question, there are several different types of decisions that may be needed to assign a standard atomic weight and uncertainty [7]. For mononuclidic elements like fluorine and phosphorus, the situation is relatively simple; the standard atomic weights are equal to the atomic masses as reported by the International Union of Pure and Applied Physics (IUPAP). In these cases, periodic changes to the values and uncertainties in atomic weights result from improved measurements of the atomic masses. For polyisotopic elements, the atomic weights may be different in different substances and the selection of the standard atomic weight is more complex. With minor exceptions to be covered by footnotes, the standard atomic weights and their uncertainties are intended to apply to almost all samples from natural terrestrial occurrences as well as to samples found in laboratories involved in chemical investigations, technological applications, or in materials of commerce.

In the recommendation of standard atomic weights, CIAAW generally has not attempted to estimate the average or composite isotopic composition of the Earth or of any subset of terrestrial materials. Instead, the Commission has attempted to find a single value and symmetrical uncertainty that would include almost all substances likely to be encountered, especially in the laboratory and in industry. Excluded from consideration in the standard atomic weights are most materials with deliberately altered isotopic compositions, extraterrestrial materials, and anomalous occurrences such as the Oklo natural nuclear reactor. The uncertainty $U[A_r(E)]$ for a given standard atomic weight is given in parentheses following the last significant figure to which it is attributed in Tables 1, 2, 4, and 5. If there is no specific statement on the distribution of possible values, then the distribution should be regarded as a rectangular distribution. The interval $A_r(E)–U[A_r(E)]$ to $A_r(E)+U[A_r(E)]$ may be expected to encompass almost all samples from natural terrestrial occurrences as well as specimens and reagents found in laboratories involved in chemical investigations, technological applications, and in materials of commerce.

Variations in the relative amounts of isotopes of the elements in different materials commonly can be measured with greater precision than the ratios of the amounts of the isotopes (commonly termed an "absolute measurement"). For this reason, there are essentially four different categories of elements with contrasting constraints on their standard atomic weights:

1. mononuclidic
2. polynuclidic with no evidence for natural variation
3. polynuclidic with evidence of variation in the amounts of the isotopes within the uncertainties of the best absolute measurement
4. polynuclidic with variation in the amounts of the isotopes exceeding the uncertainties of the best absolute measurement

The footnote "r", referring to standard atomic weights whose uncertainties reflect variation, applies only to category 4. Elements in category 3 may enter category 4 as more precise absolute determinations are made. Similarly, elements in category 2 can advance to category 3 as measurements improve. Within category 4, the footnote "g" refers to the subset of chemical elements for which the standard atomic weight and its uncertainties do not include all known variations. Thus, the footnotes "g" and "r" could occur together, or either one could occur alone.

For all elements for which a change in the value of A_r(E) or its uncertainty, $U[A_r(E)]$ (in parentheses, following the last significant figure to which it is attributed) is recommended, the Commission

by custom makes a statement on the reason for the change and includes a list of past recommended values over a period in excess of the last 100 years, which are taken from [7]. Values before the formation of the International Committee on Atomic Weights in 1900 come from [8].

The names and symbols for those elements with atomic numbers 112 to 118 referred to in the following tables, are systematic and based on the atomic numbers of the elements recommended for provisional use by the IUPAC publication "Nomenclature of Inorganic Chemistry" [9]. These systematic names and symbols will be replaced by a permanent name approved by IUPAC, once the priority of discovery is established and the name suggested by the discoverers is examined, reviewed, and accepted. The systematic name is derived directly from the atomic number of the element using the following numerical roots:

1 un	2 bi	3 tri	4 quad	5 pent
6 hex	7 sept	8 oct	9 enn	0 nil

The roots are put together in the order of the digits that make up the atomic number and terminated by "ium" to spell out the name. The final "n" of "enn" is deleted when it occurs before "nil", and the "i" of "bi" and of "tri" is deleted when it occurs before "ium".

Table 1 Standard atomic weights 2007.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights of many elements are not invariant, but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this table elaborate the types of variation that may occur for individual elements and that may be larger than the listed uncertainties of values of $A_r(E)$. Names of elements with atomic numbers 112 to 118 are provisional.

Alphabetical order in English				
Element name	Symbol	Atomic number	Atomic weight	Footnotes
actinium*	Ac	89		
aluminium (aluminum)	Al	13	26.981 538 6(8)	
americium*	Am	95		
antimony	Sb	51	121.760(1)	g
argon	Ar	18	39.948(1)	g r
arsenic	As	33	74.921 60(2)	
astatine*	At	85		
barium	Ba	56	137.327(7)	
berkelium*	Bk	97		
beryllium	Be	4	9.012 182(3)	
bismuth	Bi	83	208.980 40(1)	
bohrium*	Bh	107		
boron	B	5	10.811(7)	g m r
bromine	Br	35	79.904(1)	
cadmium	Cd	48	112.411(8)	g
caesium (cesium)	Cs	55	132.905 451 9(2)	
calcium	Ca	20	40.078(4)	g
californium*	Cf	98		
carbon	C	6	12.0107(8)	g r
cerium	Ce	58	140.116(1)	g
chlorine	Cl	17	35.453(2)	g m r

(*continues on next page*)

Table 1 (*Continued*).

Alphabetical order in English				
Element name	Symbol	Atomic number	Atomic weight	Footnotes
chromium	Cr	24	51.996 1(6)	
cobalt	Co	27	58.933 195(5)	
copper	Cu	29	63.546(3)	r
curium*	Cm	96		
darmstadtium*	Ds	110		
dubnium*	Db	105		
dysprosium	Dy	66	162.500(1)	g
einsteinium*	Es	99		
erbium	Er	68	167.259(3)	g
europium	Eu	63	151.964(1)	g
fermium*	Fm	100		
fluorine	F	9	18.998 4032(5)	
francium*	Fr	87		
gadolinium	Gd	64	157.25(3)	g
gallium	Ga	31	69.723(1)	
germanium	Ge	32	72.64(1)	
gold	Au	79	196.966 569(4)	
hafnium	Hf	72	178.49(2)	
hassium*	Hs	108		
helium	He	2	4.002 602(2)	g r
holmium	Ho	67	164.930 32(2)	
hydrogen	H	1	1.007 94(7)	g m r
indium	In	49	114.818(3)	
iodine	I	53	126.904 47(3)	
iridium	Ir	77	192.217(3)	
iron	Fe	26	55.845(2)	
krypton	Kr	36	83.798(2)	g m
lanthanum	La	57	138.905 47(7)	g
lawrencium*	Lr	103		
lead	Pb	82	207.2(1)	g r
lithium	Li	3	[6.941(2)]†	g m r
lutetium	Lu	71	174.9668(1)	g
magnesium	Mg	12	24.3050(6)	
manganese	Mn	25	54.938 045(5)	
meitnerium*	Mt	109		
mendelevium*	Md	101		
mercury	Hg	80	200.59(2)	
molybdenum	Mo	42	95.96(2)	g r
neodymium	Nd	60	144.242(3)	g
neon	Ne	10	20.1797(6)	g m
neptunium*	Np	93		
nickel	Ni	28	58.6934(4)	r
niobium	Nb	41	92.906 38(2)	
nitrogen	N	7	14.0067(2)	g r
nobelium*	No	102		
osmium	Os	76	190.23(3)	g
oxygen	O	8	15.9994(3)	g r

(*continues on next page*)

Table 1 (*Continued*).

Alphabetical order in English				
Element name	Symbol	Atomic number	Atomic weight	Footnotes
palladium	Pd	46	106.42(1)	g
phosphorus	P	15	30.973 762(2)	
platinum	Pt	78	195.084(9)	
plutonium*	Pu	94		
polonium*	Po	84		
potassium	K	19	39.0983(1)	
praseodymium	Pr	59	140.907 65(2)	
promethium*	Pm	61		
protactinium*	Pa	91	231.035 88(2)	
radium*	Ra	88		
radon*	Rn	86		
roentgenium*	Rg	111		
rhenium	Re	75	186.207(1)	
rhodium	Rh	45	102.905 50(2)	
rubidium	Rb	37	85.4678(3)	g
ruthenium	Ru	44	101.07(2)	g
rutherfordium*	Rf	104		
samarium	Sm	62	150.36(2)	g
scandium	Sc	21	44.955 912(6)	
seaborgium*	Sg	106		
selenium	Se	34	78.96(3)	r
silicon	Si	14	28.0855(3)	r
silver	Ag	47	107.8682(2)	g
sodium	Na	11	22.989 769 28(2)	
strontium	Sr	38	87.62(1)	g r
sulfur	S	16	32.065(5)	g r
tantalum	Ta	73	180.947 88(2)	
technetium*	Tc	43		
tellurium	Te	52	127.60(3)	g
terbium	Tb	65	158.925 35(2)	
thallium	Tl	81	204.3833(2)	
thorium*	Th	90	232.038 06(2)	g
thulium	Tm	69	168.934 21(2)	
tin	Sn	50	118.710(7)	g
titanium	Ti	22	47.867(1)	
tungsten	W	74	183.84(1)	
ununbium*	Uub	112		
ununhexium*	Uuh	116		
ununoctium*	Uuo	118		
ununpentium*	Uup	115		
ununquadium*	Uuq	114		
ununtrium*	Uut	113		
uranium*	U	92	238.028 91(3)	g m
vanadium	V	23	50.9415(1)	
xenon	Xe	54	131.293(6)	g m
ytterbium	Yb	70	173.054(5)	g
yttrium	Y	39	88.905 85(2)	

(*continues on next page*)

Table 1 (*Continued*).

Alphabetical order in English				
Element name	Symbol	Atomic number	Atomic weight	Footnotes
zinc	Zn	30	65.38(2)	r
zirconium	Zr	40	91.224(2)	g

*Element has no stable nuclides. One or more well-known isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

†Commercially available Li materials have atomic weights that range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

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 stated uncertainty.

m Modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. 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 and uncertainty should be applicable to normal material.

Table 2 Standard atomic weights 2007.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights of many elements are not invariant, but depend on the origin and treatment of the material. The standard values of A_r(E) and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this table elaborate the types of variation that may occur for individual elements and that may be larger than the listed uncertainties of values of A_r(E). Names of elements with atomic number 112 to 118 are provisional.

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
1	hydrogen	H	1.007 94(7)	g m r
2	helium	He	4.002 602(2)	g r
3	lithium	Li	[6.941(2)]†	g m r
4	beryllium	Be	9.012 182(3)	
5	boron	B	10.811(7)	g m r
6	carbon	C	12.0107(8)	g r
7	nitrogen	N	14.0067(2)	g r
8	oxygen	O	15.9994(3)	g r
9	fluorine	F	18.998 4032(5)	
10	neon	Ne	20.1797(6)	g m
11	sodium	Na	22.989 769 28(2)	
12	magnesium	Mg	24.3050(6)	
13	aluminium (aluminum)	Al	26.981 5386(8)	
14	silicon	Si	28.0855(3)	r
15	phosphorus	P	30.973 762(2)	
16	sulfur	S	32.065(5)	g r
17	chlorine	Cl	35.453(2)	g m r
18	argon	Ar	39.948(1)	g r
19	potassium	K	39.0983(1)	

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
20	calcium	Ca	40.078(4)	g
21	scandium	Sc	44.955 912(6)	
22	titanium	Ti	47.867(1)	
23	vanadium	V	50.9415(1)	
24	chromium	Cr	51.9961(6)	
25	manganese	Mn	54.938 045(5)	
26	iron	Fe	55.845(2)	
27	cobalt	Co	58.933 195(5)	
28	nickel	Ni	58.6934(4)	r
29	copper	Cu	63.546(3)	r
30	zinc	Zn	65.38(2)	r
31	gallium	Ga	69.723(1)	
32	germanium	Ge	72.64(1)	
33	arsenic	As	74.921 60(2)	
34	selenium	Se	78.96(3)	r
35	bromine	Br	79.904(1)	
36	krypton	Kr	83.798(2)	g m
37	rubidium	Rb	85.4678(3)	g
38	strontium	Sr	87.62(1)	g r
39	yttrium	Y	88.905 85(2)	
40	zirconium	Zr	91.224(2)	g
41	niobium	Nb	92.906 38(2)	
42	molybdenum	Mo	95.96(2)	g r
43	technetium*	Tc		
44	ruthenium	Ru	101.07(2)	g
45	rhodium	Rh	102.905 50(2)	
46	palladium	Pd	106.42(1)	g
47	silver	Ag	107.8682(2)	g
48	cadmium	Cd	112.411(8)	g
49	indium	In	114.818(3)	
50	tin	Sn	118.710(7)	g
51	antimony	Sb	121.760(1)	g
52	tellurium	Te	127.60(3)	g
53	iodine	I	126.904 47(3)	
54	xenon	Xe	131.293(6)	g m
55	caesium (cesium)	Cs	132.905 451 9(2)	
56	barium	Ba	137.327(7)	
57	lanthanum	La	138.905 47(7)	g
58	cerium	Ce	140.116(1)	g
59	praseodymium	Pr	140.907 65(2)	
60	neodymium	Nd	144.242(3)	g
61	promethium*	Pm		
62	samarium	Sm	150.36(2)	g
63	europium	Eu	151.964(1)	g
64	gadolinium	Gd	157.25(3)	g
65	terbium	Tb	158.925 35(2)	
66	dysprosium	Dy	162.500(1)	g
67	holmium	Ho	164.930 32(2)	

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
68	erbium	Er	167.259(3)	g
69	thulium	Tm	168.934 21(2)	
70	ytterbium	Yb	173.054(5)	g
71	lutetium	Lu	174.9668(1)	g
72	hafnium	Hf	178.49(2)	
73	tantalum	Ta	180.947 88(2)	
74	tungsten	W	183.84(1)	
75	rhenium	Re	186.207(1)	
76	osmium	Os	190.23(3)	g
77	iridium	Ir	192.217(3)	
78	platinum	Pt	195.084(9)	
79	gold	Au	196.966 569(4)	
80	mercury	Hg	200.59(2)	
81	thallium	Tl	204.3833(2)	
82	lead	Pb	207.2(1)	g r
83	bismuth	Bi	208.980 40(1)	
84	polonium*	Po		
85	astatine*	At		
86	radon*	Rn		
87	francium*	F		
88	radium*	Ra		
89	actinium*	Ac		
90	thorium*	Th	232.038 06(2)	g
91	protactinium*	Pa	231.035 88(2)	
92	uranium*	U	238.028 91(3)	g m
93	neptunium*	Np		
94	plutonium*	Pu		
95	americium*	Am		
96	curium*	Cm		
97	berkelium*	Bk		
98	californium*	Cf		
99	einsteinium*	Es		
100	fermium*	Fm		
101	mendelevium*	Md		
102	nobelium*	No		
103	lawrencium*	Lr		
104	rutherfordium*	Rf		
105	dubnium*	Db		
106	seaborgium*	Sg		
107	bohrium*	Bh		
108	hassium*	Hs		
109	meitnerium*	Mt		
110	darmstadtium*	Ds		
111	roentgenium*	Rg		
112	ununbium*	Uub		
113	ununtrium*	Uut		
114	ununquadium*	Uuq		
115	ununpentium*	Uup		

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
116	ununhexium*	Uuh		
118	ununoctium*	Uuo		

*Element has no stable nuclides. One or more well-known isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

†Commercially available Li materials have atomic weights that range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

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 stated uncertainty.

m Modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. 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 and uncertainty should be applicable to normal material.

Table 3 Relative atomic masses and half-lives of selected radionuclides. Listing of particular nuclides for elements numbered 112 and above in Table 3 does not imply any priority of the discovery of those elements on the part of the Commission.

[Prepared, as in previous years, by N. E. Holden, a former Commission member; a = year; d = day; h = hour; min = minute; s = second. Names of elements with atomic number 112 to 118 are provisional.]

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
43	technetium	Tc	97	96.9064	$4.21(16) \times 10^6$	a
			98	97.9072	$6.6(10) \times 10^6$	a
			99	98.9063	$2.1(3) \times 10^5$	a
61	promethium	Pm	145	144.9127	17.7(4)	a
			146	145.9147	5.53(5)	a
			147	146.9151	2.623(3)	a
84	polonium	Po	208	207.9812	2.90(1)	a
			209	208.9824	$1.3(2) \times 10^2$	a
			210	209.9829	138.4(1)	d
85	astatine	At	210	209.9871	8.1(4)	h
			211	210.9875	7.21(1)	h
86	radon	Rn	210	209.9897	2.4(1)	h
			211	210.9906	14.6(2)	h
			222	222.0176	3.823(4)	d
87	francium	Fr	212	211.9962	20.0(6)	min
			222	222.0176	14.2(3)	min
			223	223.0197	22.0(1)	min
88	radium	Ra	226	226.0254	1599(4)	a
			228	228.0311	5.76(3)	a
89	actinium	Ac	225	225.0232	10.0(1)	d
			227	227.0278	21.77(2)	a
90	thorium	Th	230	230.0331	$7.54(3) \times 10^6$	a
			232	232.0381	$1.40(1) \times 10^{10}$	a

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Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
91	protactinium	Pa	231	231.0359	$3.25(1) \times 10^4$	a
			233	233.04025	27.0(1)	d
92	uranium	U	233	233.0396	$1.592(2) \times 10^5$	a
			234	234.0410	$2.455(6) \times 10^5$	a
			235	235.0439	$7.04(1) \times 10^8$	a
			236	236.0456	$2.342(4) \times 10^7$	a
			238	238.0508	$4.468(3) \times 10^9$	a
93	neptunium	Np	236	236.0466	$1.54(6) \times 10^5$	a
			237	237.0482	$2.14(1) \times 10^6$	a
94	plutonium	Pu	238	238.0496	87.7(1)	a
			239	239.0522	$2.410(3) \times 10^4$	a
			240	240.0538	$6.56(1) \times 10^3$	a
			241	241.0569	14.4(1)	a
			242	242.0587	$3.75(2) \times 10^5$	a
			244	244.0642	$8.00(9) \times 10^7$	a
95	americium	Am	241	241.0568	432.7(6)	a
			243	243.0614	$7.37(2) \times 10^3$	a
96	curium	Cm	243	243.0614	29.1(1)	a
			244	244.0628	18.1(1)	a
			245	245.0655	$8.48(6) \times 10^3$	a
			246	246.0672	$4.76(4) \times 10^3$	a
			247	247.0704	$1.56(5) \times 10^7$	a
			248	248.0723	$3.48(6) \times 10^5$	a
97	berkelium	Bk	247	247.0703	$1.4(3) \times 10^3$	a
			249	249.0750	$3.20(3) \times 10^2$	d
98	californium	Cf	249	249.0749	351(2)	a
			250	250.0764	13.1(1)	a
			251	251.0796	$9.0(5) \times 10^2$	a
			252	252.0816	2.65(1)	a
99	einsteinium	Es	252	252.0830	472(2)	d
			254	254.0880	276(1)	d
100	fermium	Fm	253	253.0852	3.0(1)	d
			257	257.0951	100.5(2)	d
101	mendelevium	Md	258	258.0984	51.5(3)	d
			260	260.1037	27.8(3)	d
102	nobelium	No	255	255.0932	3.1(2)	min
			259	259.1010	58(5)	min
103	lawrencium	Lr	251	251.0944	~39	min
			261	261.1069	~40	min
			262	262.1096	3.6(3)	h
104	rutherfordium	Rf	265	265.1167	13	h
			267	267.122	~1	h
105	dubnium	Db	267	267.1224	~1.2	h
			268	268.125	1.2(4)	d
106	seaborgium	Sg	265	265.1211	~15	s
			271	271.133	~2	min
107	bohrium	Bh	267	267.1277	~17	s
			272		~1	min

(*continues on next page*)

Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
108	hassium	Hs	269	269.1341	~10	s
			277	277.150	11	min
109	meitnerium	Mt	268	268.1387	~0.03	s
			276	276.151	~0.7	s
110	darmstadtium	Ds	280	280.160	~7.6	s
			281	281.162	~11	s
111	roentgenium	Rg	279	279.162	~0.17	s
			280	280.164	~3.6	s
112	ununbium	Uub	283	283.172	~4	s
			285	285.174	~29	s
113	ununtrium	Uut	283	283.176	~0.1	s
			284	284.178	~0.48	s
114	ununquadium	Uuq	288	288.186	0.8(3)	s
			289	289.189	~2.6	s
115	ununpentium	Uup	287	287.191	~0.03	s
			288	288.192	~0.09	s
116	ununhexium	Uuh	291		$\sim 18 \times 10^{-3}$	s
			292	292.200	$\sim 18 \times 10^{-3}$	s
			293		0.06(5)	s
118	ununoctium	Uuo	294		$\sim 0.89 \times 10^{-3}$	s

Table 4 Standard atomic weights 2007 abridged to four significant digits. [Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights of many elements are not invariant, but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The last significant figure of each tabulated value is considered reliable to ±1 except when a larger single digit uncertainty is inserted in parentheses following the atomic weight.

Atomic number	Element name	Symbol	Atomic weight
1	hydrogen	H	1.008
2	helium	He	4.003
3	lithium	Li	6.941(2)[†]
4	beryllium	Be	9.012
5	boron	B	10.81[#]
6	carbon	C	12.01
7	nitrogen	N	14.01
8	oxygen	O	16.00
9	fluorine	F	19.00
10	neon	Ne	20.18
11	sodium	Na	22.99
12	magnesium	Mg	24.31
13	aluminium (aluminum)	Al	26.98
14	silicon	Si	28.09

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Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
15	phosphorus	P	30.97
16	sulfur	S	32.07#
17	chlorine	Cl	35.45
18	argon	Ar	39.95
19	potassium	K	39.10
20	calcium	Ca	40.08#
21	scandium	Sc	44.96
22	titanium	Ti	47.87
23	vanadium	V	50.94
24	chromium	Cr	52.00
25	manganese	Mn	54.94
26	iron	Fe	55.85
27	cobalt	Co	58.93
28	nickel	Ni	58.69
29	copper	Cu	63.55
30	zinc	Zn	65.38(2)
31	gallium	Ga	69.72
32	germanium	Ge	72.64
33	arsenic	As	74.92
34	selenium	Se	78.96(3)
35	bromine	Br	79.90
36	krypton	Kr	83.80#
37	rubidium	Rb	85.47#
38	strontium	Sr	87.61#
39	yttrium	Y	88.91
40	zirconium	Zr	91.22#
41	niobium	Nb	92.91
42	molybdenum	Mo	95.96(2)#
43	technetium*	Tc	
44	ruthenium	Ru	101.1#
45	rhodium	Rh	102.9
46	palladium	Pd	106.4#
47	silver	Ag	107.9#
48	cadmium	Cd	112.4#
49	indium	In	114.8
50	tin	Sn	118.7#
51	antimony	Sb	121.8#
52	tellurium	Te	127.6#
53	iodine	I	126.9
54	xenon	Xe	131.3#
55	caesium (cesium)	Cs	132.9
56	barium	Ba	137.3
57	lanthanum	La	138.9
58	cerium	Ce	140.1#
59	praseodymium	Pr	140.9
60	neodymium	Nd	144.2#
61	promethium*	Pm	
62	samarium	Sm	150.4#
63	europium	Eu	152.0#

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Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
64	gadolinium	Gd	157.3#
65	terbium	Tb	158.9
66	dysprosium	Dy	162.5#
67	holmium	Ho	164.9
68	erbium	Er	167.3#
69	thulium	Tm	168.9
70	ytterbium	Yb	173.1#
71	lutetium	Lu	175.0
72	hafnium	Hf	178.5
73	tantalum	Ta	180.9
74	tungsten	W	183.9
75	rhenium	Re	186.2
76	osmium	Os	190.2
77	iridium	Ir	192.2
78	platinum	Pt	195.1
79	gold	Au	197.0
80	mercury	Hg	200.6
81	thallium	Tl	204.4
82	lead	Pb	207.2#
83	bismuth	Bi	209.0
84	polonium*	Po	
85	astatine*	At	
86	radon*	Rn	
87	francium*	Fr	
88	radium*	Ra	
89	actinium*	Ac	
90	thorium*	Th	232.0
91	protactinium*	Pa	231.0
92	uranium*	U	238.0#
93	neptunium*	Np	
94	plutonium*	Pu	
95	americium*	Am	
96	curium*	Cm	
97	berkelium*	Bk	
98	californium*	Cf	
99	einsteinium*	Es	
100	fermium*	Fm	
101	mendelevium*	Md	
102	nobelium*	No	
103	lawrencium*	Lr	
104	rutherfordium*	Rf	
105	dubnium*	Db	
106	seaborgium*	Sg	
107	bohrium*	Bh	
108	hassium*	Hs	
109	meitnerium*	Mt	
110	darmstadtium*	Ds	
111	roentgenium*	Rg	
112	ununbium*	Uub	

(*continues on next page*)

Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
113	ununtrium*	Uut	
114	ununquadium*	Uuq	
115	ununpentium*	Uup	
116	ununhexium*	Uuh	
118	ununoctium*	Uuo	

*Element has no stable nuclides. One or more well-known isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

†Commercially available Li materials have atomic weights that range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

#Values may differ from the atomic weights of the relevant elements in some naturally occurring samples because of a variation in the relative isotopic abundance.

Table 5 Standard atomic weights 2007 abridged to five significant digits.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

Atomic weights are quoted here to five significant figures unless the dependable accuracy is further limited by either the combined uncertainties of the best published atomic weight determinations, or by the variability of isotopic composition in normal terrestrial occurrences (the latter applies to the elements annotated "r"). The last significant figure of each tabulated value is considered reliable to ±1 except when a larger single digit uncertainty is inserted in parentheses following the atomic weight. Neither the highest nor the lowest actual atomic weight of any normal sample is thought likely to differ from the tabulated values by more than one assigned uncertainty. However, the tabulated values do not apply either to samples of highly exceptional isotopic composition arising from most unusual geological occurrences (for elements annotated "g") or to those whose isotopic composition has been artificially altered. Such might even be found in commerce without disclosure of that modification (for elements annotated "m"). Elements with no stable isotope do not have an atomic weight and such entries have a blank in the atomic weight column. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition and for these an atomic weight value is tabulated. For more detailed information, users should refer to the full IUPAC Table of Standard Atomic Weights. Names of elements with atomic number 112 to 118 are provisional.

Order of atomic number

Atomic number	Element name	Symbol	Atomic weight	Footnotes
1	hydrogen	H	1.0079	g m
2	helium	He	4.0026	
3	lithium	Li	6.941(2)†	g m r
4	beryllium	Be	9.0122	
5	boron	B	10.811(7)	g m r
6	carbon	C	12.011	g r
7	nitrogen	N	14.007	
8	oxygen	O	15.999	
9	fluorine	F	18.998	
10	neon	Ne	20.180	m

(*continues on next page*)

Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
11	sodium	Na	22.990	
12	magnesium	Mg	24.305	
13	aluminium (aluminum)	Al	26.982	
14	silicon	Si	28.086	
15	phosphorus	P	30.974	
16	sulfur	S	32.065(5)	g r
17	chlorine	Cl	35.453(2)	m
18	argon	Ar	39.948	g r
19	potassium	K	39.098	g
20	calcium	Ca	40.078(4)	g
21	scandium	Sc	44.956	
22	titanium	Ti	47.867	
23	vanadium	V	50.942	
24	chromium	Cr	51.996	
25	manganese	Mn	54.938	
26	iron	Fe	55.845(2)	
27	cobalt	Co	58.933	
28	nickel	Ni	58.693	r
29	copper	Cu	63.546(3)	r
30	zinc	Zn	65.38(2)	r
31	gallium	Ga	69.723	
32	germanium	Ge	72.64	
33	arsenic	As	74.922	
34	selenium	Se	78.96(3)	r
35	bromine	Br	79.904	
36	krypton	Kr	83.798(2)	g m
37	rubidium	Rb	85.468	
38	strontium	Sr	87.62	g r
39	yttrium	Y	88.906	
40	zirconium	Zr	91.224(2)	g
41	niobium	Nb	92.906(2)	
42	molybdenum	Mo	95.96(2)	g r
43	technetium*	Tc		
44	ruthenium	Ru	101.07(2)	g
45	rhodium	Rh	102.91	
46	palladium	Pd	106.42	g
47	silver	Ag	107.87	g
48	cadmium	Cd	112.41	
49	indium	In	114.82	
50	tin	Sn	118.71	
51	antimony	Sb	121.76	g
52	tellurium	Te	127.60(3)	g
53	iodine	I	126.90	
54	xenon	Xe	131.29	g m
55	caesium (cesium)	Cs	132.91	
56	barium	Ba	137.33	
57	lanthanum	La	138.91	
58	cerium	Ce	140.12	g

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Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
59	praseodymium	Pr	140.91	
60	neodymium	Nd	144.24	g
61	promethium*	Pm		
62	samarium	Sm	150.36(2)	g
63	europium	Eu	151.96	g
64	gadolinium	Gd	157.25(3)	g
65	terbium	Tb	158.93	
66	dysprosium	Dy	162.50	g
67	holmium	Ho	164.93	
68	erbium	Er	167.26	g
69	thulium	Tm	168.93	
70	ytterbium	Yb	173.05	g
71	lutetium	Lu	174.97	g
72	hafnium	Hf	178.49(2)	
73	tantalum	Ta	180.95	
74	tungsten	W	183.84	
75	rhenium	Re	186.21	
76	osmium	Os	190.23(3)	g
77	iridium	Ir	192.22	
78	platinum	Pt	195.08	
79	gold	Au	196.97	
80	mercury	Hg	200.59(2)	
81	thallium	Tl	204.38	
82	lead	Pb	207.2	g r
83	bismuth	Bi	208.98	
84	polonium*	Po		
85	astatine*	At		
86	radon*	Rn		
87	francium*	Fr		
88	radium*	Ra		
89	actinium*	Ac		
90	thorium*	Th	232.04	g
91	protactinium*	Pa	231.04	
92	uranium*	U	238.03	g m
93	neptunium*	Np		
94	plutonium*	Pu		
95	americium*	Am		
96	curium*	Cm		
97	berkelium*	Bk		
98	californium*	Cf		
99	einsteinium*	Es		
100	fermium*	Fm		
101	mendelevium*	Md		
102	nobelium*	No		
103	lawrencium*	Lr		
104	rutherfordium*	Rf		
105	dubnium*	Db		
106	seaborgium*	Sg		

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Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
107	bohrium*	Bh		
108	hassium*	Hs		
109	meitnerium*	Mt		
110	darmstadtium*	Ds		
111	roentgenium*	Rg		
112	ununbium*	Uub		
113	ununtrium*	Uut		
114	ununquadium*	Uuq		
115	ununpentium*	Uup		
116	ununhexium*	Uuh		
118	ununoctium*	Uuo		

*Element has no stable nuclides. One or more well-known isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

†Commercially available Li materials have atomic weights that range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

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 stated uncertainty.

m Modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. 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 and uncertainty should be applicable to normal material.

COMMENTS ON EVALUATIONS OF ATOMIC WEIGHTS AND ANNOTATIONS

The Commission regularly evaluates reports of atomic weight determinations to select the "best measurement" of the isotopic abundances of an element in a specified material. The best measurement may be defined as a set of analyses of the isotope-amount or isotope-number ratios of an element in a well-characterized, representative material with low combined uncertainty. To be considered by the Commission for evaluation, reports must be published in peer-reviewed literature, and the results should be given with sufficient detail that the Commission can reconstruct the uncertainty budget in its various components, including sample preparation, analysis of isotope-amount or isotope-number ratios, and data handling.

Criteria used to evaluate a "best measurement" include:

1. The extent to which random and systematic errors have been assessed and documented in the report. The Commission seeks evidence that mass spectrometer linearity, mass spectrometric fractionation of ions of varying masses, memory, baseline, interference between ions, sample purity and preparation effects, and statistical assessment of data were carried out properly. Preference is given to measurements that are fully calibrated with synthetic mixtures of isotopes of the element of interest, covering the isotopic abundance variations of naturally occurring materials over the range of the masses of the isotopes in the material being analyzed.
2. The relevance and availability of the analyzed material for the scientific community involved in isotopic measurements and calibrations. Preference is given to analyses of chemically stable materials that are distributed internationally as isotopic reference materials, e.g., by the U.S. National Institute of Standards and Technology (NIST), the European Institute of Reference Materials and

Measurements (IRMM), the International Atomic Energy Agency (IAEA), etc. or to isotopically unfractionated representatives of homogeneous terrestrial materials.

New analytical techniques for isotope-amount ratio determinations have made a significant impact on how data are collected and reported. In the case of Zn, for the first time in the history of the Commission, a standard atomic weight was recommended based on a new best measurement determined by multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS).

Following are brief descriptions of the changes in the Table of Standard Atomic Weights resulting from the Commission meeting in 2007.

Lutetium

The Commission has changed the recommended value for the standard atomic weight of lutetium, A_r(Lu), to 174.9668(1), based on a recent measurement by [10]. The measurement does not qualify for a fully calibrated measurement because the linearity of the instrument was verified for a certified potassium isotopic reference material (NIST 985), but not Lu. Sr and Pb isotopic compositions were also employed to check for linearity. The instrumental isotopic fractionation of Lu was corrected using a fractionation factor determined for Yb [11]. The relatively low abundance of the ^{176}Lu in this two-isotope element means that even when applying the Commission's standard uncertainty protocol of increasing the reported uncertainty by 100 % because of an uncalibrated fractionation factor, the corrections still result in a standard atomic weight uncertainty reduction of a factor of 10 over previous determined values. The ^{176}Lu/^{175}Lu isotope-amount ratio, $n(^{176}\text{Lu})/n(^{175}\text{Lu})$, reported by [10] is also determined by the Commission to be the best measurement from a single terrestrial source and the isotope amount abundances are $x(^{175}\text{Lu}) = 0.974\,013(12)$ and $x(^{176}\text{Lu}) = 0.025\,987(12)$. The previous atomic weight value A_r(Lu) = 174.967(1), recommended in 1981, was based on the mass spectrometric measurements of McCulloch et al. [12]. Historical values of A_r(Lu) include [8]: 1909, 174.0; 1916, 175.0; 1940, 174.99; 1961, 174.97; 1969, 174.97(1); 1977, 174.967(3); 1981, 174.967(1).

Molybdenum

The Commission has changed the recommended value for the standard atomic weight of molybdenum, A_r(Mo), to 95.96(2), based on the first calibrated measurements with synthetic isotope mixtures using a thermal ionization mass spectrometer (TIMS) [13]. Although the authors of ref. [13] reduced uncertainties with renormalization of the ratios using the calculated fractionation factors of $N(^{100}\text{Mo})/N(^{95}\text{Mo})$, the Commission adopted the conventional method of uncertainty calculations using the raw data and assigned the uncertainty of 0.02. The new value agrees marginally with the previous value of A_r(Mo) of 95.94(2) with its enlarged uncertainty recommended in 2001 [14]. The new calibrated values for the isotope amount abundances of Mo determined by the Commission to be the best measurement from a single terrestrial source are $x(^{92}\text{Mo}) = 0.145\,25(15)$, $x(^{94}\text{Mo}) = 0.091\,514(74)$, $x(^{95}\text{Mo}) = 0.158\,375(98)$, $x(^{96}\text{Mo}) = 0.166\,72(19)$, $x(^{97}\text{Mo}) = 0.095\,991(73)$, $x(^{98}\text{Mo}) = 0.243\,91(18)$, and $x(^{100}\text{Mo}) = 0.098\,24(50)$. The previous value of A_r(Mo) was based on chemical ratio measurements [15], and the evaluated uncertainty of 0.03 was later included in 1969. The Commission reduced the uncertainty to 0.01 in 1975 but reevaluated and changed it to 0.02 in 2001. Historical values of A_r(Mo) include [8]: 1882, 95.75; 1894, 96; 1896, 95.98; 1897, 95.99; 1900, 96; 1938, 95.95; 1961, 95.94; 1969, 95.94(3); 1975, 95.94(1); 2001, 95.94(2).

Nickel

The Commission has changed the recommended value for the standard atomic weight of nickel, A_r(Ni), to 58.693 4(4), based on the measurements published in [16]. The authors measured Ni isotope-amount

ratios on an MC-ICP-MS with external normalization using doped Cu (SRM 976). They found that the atomic weights of a Ni reagent and nickel sulfide ore were outside of the range of values in the previous Table of Standard Atomic Weights. The footnotes "r" in Tables 1, 2, and 5 arise because the variation in the atomic weights of Ni from normal sources limit the precision to which A_r(Ni) may be reported. Historical values of A_r(Ni) include [8]: 1892, 58.06; 1894, 58.7; 1896, 58.69; 1900, 58.7; 1909, 58.68; 1925, 58.69; 1955, 58.71; 1969, 58.71(3); 1973, 58.70(1); 1979, 58.69(1); 1989, 58.693 4(2).

Ytterbium

The Commission has changed the recommended value for the standard atomic weight of ytterbium, A_r(Yb), to 173.054(5), based on the first calibrated measurements with synthetic isotope mixtures using a TIMS [11]. The isotopic composition of Yb reported in [11] is also determined by the Commission to be the best measurement from a single terrestrial source. The isotope amount abundances are $x(^{168}\text{Yb}) = 0.001\,232(4)$, $x(^{170}\text{Yb}) = 0.029\,82(6)$, $x(^{171}\text{Yb}) = 0.140\,86(20)$, $x(^{172}\text{Yb}) = 0.216\,86(19)$, $x(^{173}\text{Yb}) = 0.161\,03(9)$, $x(^{174}\text{Yb}) = 0.320\,25(12)$, $x(^{176}\text{Yb}) = 0.129\,95(13)$. The previous value of A_r(Yb) of 173.04(3) was originally based on the chemical determination from 1934 and was confirmed by mass spectrometric data in [17,18] as summarized by the Commission in 1961 [19]. The evaluated uncertainty was added for the first time in 1969. Historical values of A_r(Yb) include [8]: 1882, 173.16; 1894, 173.0; 1897, 173.19; 1900, 173.2; 1903, 173; 1909, 172.0; 1916, 173.5; 1925, 173.6; 1931, 173.5; 1934, 173.04; 1969, 173.04(3).

Zinc

The Commission has changed the recommended value for the standard atomic weight of zinc, A_r(Zn), to 65.38(2) based on a fully calibrated measurement [20]. The authors calibrated their instrument using synthetic mixtures of highly enriched Zn isotopes. Their value for A_r(Zn) measured from the isotope reference material IRMM-3702 is 65.377 77(22), which is significantly different from the previous IUPAC value of 65.409(4) [1,2]. The latter is based on a calibrated measurement by Chang et al. using TIMS [21]. A calibrated MC-ICP-MS measurement by Tanimizu et al. [22] found an atomic weight of Zn of 65.3756(40), also significantly different from the earlier value [21]. It is important to note that the atomic weight of Zn of 65.377(3) determined much earlier using coulometric techniques [23] is in good agreement with the measurement by Ponzevera et al. [20] and Tanimizu et al. [22]. Both [20,22] proposed that the atomic weight reported in Chang et al. [21] was affected by a systematic measurement bias. Ponzevera et al. analyzed an aliquot of the same material as Chang et al. (IM-1009 in ref. [20] and Sample 2 in ref. [21]) and found a significant difference between their MC-ICP-MS result and the value reported in Chang et al. [21].

Ponzevera et al. [20] also analyzed a commercial Zn shelf reagent (IRM-651) for its absolute isotopic composition. This measurement confirms earlier reports in the literature of significant variations in Zn isotopic composition in natural geological samples and Zn reagents. The standard atomic weight of Zn and its associated uncertainty recommended by the Commission 65.38(2) includes the reported variations in natural Zn isotopic abundances and, thus, variations in the Zn atomic weight in nature. This recommendation also includes the Zn atomic weight of 65.396(5), which was obtained by a calibrated measurement of an unspecified Zn sample by electron impact mass spectrometry [24]. The uncertainty reported in [20] was expanded to encompass known variations in the isotopic composition of Zn in natural materials. The footnotes "r" in Tables 1, 2, and 5 arise because the variations in the atomic weights of Zn from normal sources limits the precision to which A_r(Zn) may be reported. The isotope amount abundances of IRMM-3702 reported by [20] were also determined by the Commission to be the best measurement from a single terrestrial source and the isotope amount abundances are $x(^{64}\text{Zn}) = 0.491\,704(83)$, $x(^{66}\text{Zn}) = 0.277\,31(11)$, $x(^{67}\text{Zn}) = 0.040\,401(18)$, $x(^{68}\text{Zn}) = 0.184\,483(69)$, and $x(^{70}\text{Zn}) =$

0.006 106(11). Historical values of A_r(Zn) include [8]: 1882, 65.05; 1894, 65.3; 1896, 65.41; 1900, 65.4; 1909, 65.7; 1910, 65.37; 1925, 65.38; 1961, 65.37; 1969, 65.37(3); 1971, 65.38(1); 1983, 65.39(2); 2005, 65.409(4).

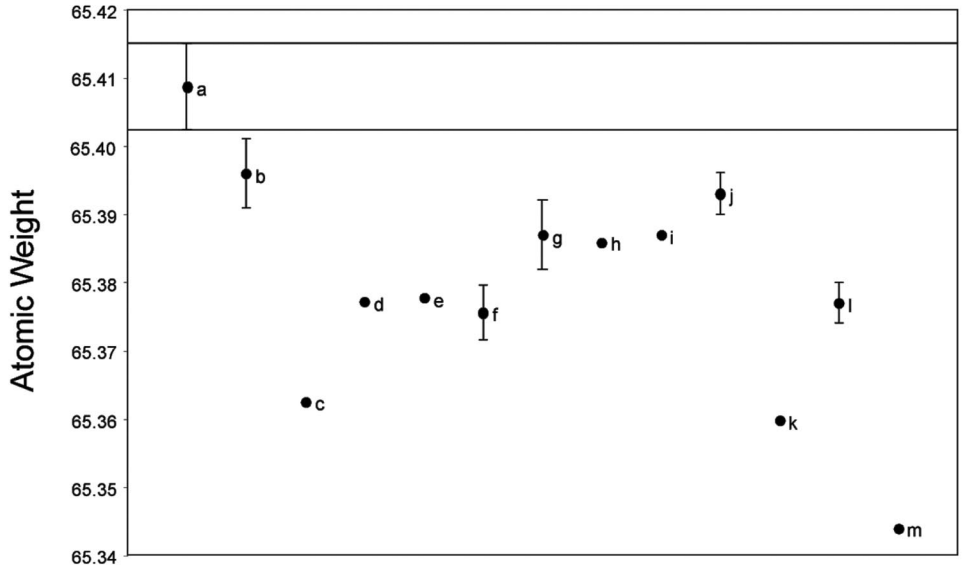

Fig. 1 Atomic weight of Zn reported in the literature. The values for A_r(Zn) measured over the past six decades do not always agree nor fall within the range recommended previously by IUPAC. The new recommended value for A_r(Zn) now covers most of the atomic weights of Zn measured in various materials. The footnote "r" in Tables 1, 2, and 5 indicates that the precision in the value of A_r(Zn) is limited by the variability in the isotopic composition measured in normally occurring materials. The data are taken from (a) Chang et al. [21] and IUPAC [1,2], (b) Rosman [24], (c) IRMM-651 [20], (d) IM-1009 [20], (e) IRMM-3702 [20], (f) Tanimizu et al. [22], (g) Leyland et al. [25], (h) Hess et al. [26], (i) Bainbridge et al. [27], (j) Hibbs [28], (k) Okamoto et al. [29], (l) Marinenko et al. [23], and (m) Konishi et al. [30]. The figure is modified from [20].

Relative atomic mass values and half-lives of selected radionuclides

For elements that have no stable or long-lived nuclides, the data on radioactive half-lives and relative atomic mass values for the nuclides of interest and importance have been evaluated, and the recommended values and uncertainties are listed in Table 3. It must be noted that the listing of particular nuclides for elements numbered 112 and above in Table 3 does not imply any priority of the discovery of those elements on the part of the Commission.

As has been the custom in the past, the Commission publishes a table of relative atomic mass values and half-lives of selected radionuclides, although the Commission has no official responsibility for the dissemination of such values. There is no general agreement on which of the nuclides of the radioactive elements is, or is likely to be judged, "important". Various criteria such as "longest half-life", "production in quantity", and "used commercially" have been applied in the past to the Commission's choice.

The information contained in this table will enable the user to calculate the atomic weights of radioactive materials with a variety of isotopic compositions. Nuclidic mass values have been taken from the 2003 atomic mass Table [6]. Some of these half-lives have already been documented [31–34].

ABRIDGED TABLES OF STANDARD ATOMIC WEIGHTS

It has been noted that the detail and the number of significant figures found in the full Table of Standard Atomic Weights (Tables 1 and 2) exceed the needs and the interests of many users, who are more concerned with the length of time during which a given table has validity to the precision limit of their interests. Tables abridged to four or five significant figures are published with the reasonable hope that not even one of the quoted values will need to be changed because of the biennial revision of the unabridged table, although the quoted uncertainties may be altered. Any change in an abridged value will likely be by only one unit in the final significant figure or by the addition of a fifth significant figure. Such constancy in these values is desirable for textbooks and numerical tables derived from atomic weight data. Standard atomic weights abridged to four and five significant figures are presented in Tables 4 and 5, respectively.

RECOMMENDATION ON THE USE OF OXYGEN IN AIR AS AN INTERNATIONAL REFERENCE STANDARD FOR REPORTING $\delta(^{17}O)$ AND $\delta(^{18}O)$ DATA

Following a proposal by Barkan and Luz [35] and acknowledging the isotopic homogeneity of atmospheric O_2, the Commission recommends that atmospheric O_2 be recognized as an international measurement standard for measurements of differences in relative O isotope-amount ratios. The relation for $\delta(^{17}O)$ is

$$\delta(^{17}\mathrm{O})_{\mathrm{B,\,Air}} = \frac{n\left(^{17}\mathrm{O}\right)_{\mathrm{B}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{B}} - n\left(^{17}\mathrm{O}\right)_{\mathrm{Air}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{Air}}}{n\left(^{17}\mathrm{O}\right)_{\mathrm{Air}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{Air}}} = \frac{r\left(^{17}\mathrm{O}\right)_{\mathrm{B}} - r\left(^{17}\mathrm{O}\right)_{\mathrm{Air}}}{r\left(^{17}\mathrm{O}\right)_{\mathrm{Air}}}$$

where $n(^{17}O)_B/n(^{16}O)_B$ and $n(^{17}O)_{Air}/n(^{16}O)_{Air}$ are the ratios of the isotope amounts of specimen B and atmospheric O_2, and $r(^{17}O)_B$ and $r(^{16}O)_{Air}$ are the isotope-amount ratios of specimen B and atmospheric O_2. In an equivalent manner, the relation for $\delta(^{18}O)$ is

$$\delta(^{18}\mathrm{O})_{\mathrm{B,\,Air}} = \frac{n\left(^{18}\mathrm{O}\right)_{\mathrm{B}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{B}} - n\left(^{18}\mathrm{O}\right)_{\mathrm{Air}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{Air}}}{n\left(^{18}\mathrm{O}\right)_{\mathrm{Air}} \Big/ n\left(^{16}\mathrm{O}\right)_{\mathrm{Air}}} = \frac{r\left(^{18}\mathrm{O}\right)_{\mathrm{B}} - r\left(^{18}\mathrm{O}\right)_{\mathrm{Air}}}{r\left(^{18}\mathrm{O}\right)_{\mathrm{Air}}}$$

Thus, atmospheric O_2 will join reference Vienna Standard Mean Ocean Water (VSMOW) and Vienna Pee Dee Belemnite (VPDB) as an international measurement standard for reporting $\delta(^{17}O)$ and $\delta(^{18}O)$ values. To be consistent with other expressions of $\delta(^{18}O)$ with respect to VSMOW or VPDB [36], $\delta(^{18}O)$ values expressed relative to atmospheric O_2 should be given on a scale normalized such that the $\delta(^{18}O)$ of the international measurement Standard Light Antarctic Precipitation (SLAP) is –55.5 ‰ relative to VSMOW. The $\delta(^{18}O)$ of atmospheric O_2 (with respect to the VSMOW-SLAP scale) has been reported as +23.88 ± 0.03 ‰ [35] and +23.8 ± 0.3 ‰ [37]. For $\delta(^{17}O)$ values, the $\delta(^{17}O)$ value of SLAP relative to VSMOW should be provided in reports of authors so that scale normalization can be performed by readers if needed.

RECOMMENDATION FOR A NEW BEST MEASUREMENT OF $n(^{40}Ar)/n(^{36}Ar)$

The Commission-recommended value for the isotope-amount ratio of Ar isotopes $n(^{40}Ar)/n(^{36}Ar)$ in air has been changed to 298.56(31) from 296.03(53) on the basis of new partially calibrated measurements [38]. The corresponding atomic weight from atmospheric Ar is indistinguishable from the previous standard atomic weight for Ar of 39.948(1) for which the uncertainty accommodates for the variability.

The new isotope-amount ratio from Lee et al. [38] is 1 % higher than the value accepted previously. This is significant in the age dating of geological systems using the Ar–K–Ca decay scheme. An accurate determination of an age depends on a reliable $n(^{40}Ar)/n(^{36}Ar)$ isotope-amount ratio of the initial argon present before the mineral became isolated and the geological clock began "ticking". Often, Ar–K–Ca dating calculations employ the $n(^{40}Ar)/n(^{36}Ar)$ isotope-amount ratio from Nier of 295.5(5) [39]. An inaccurate value for the isotope composition of the initial Ar present in the mineral would result in a systematic offset to argon ages.

RECOMMENDATIONS FOR THE INCLUSION OF SYSTEMATIC ERRORS IN THE PUBLICATION OF MASS SPECTROMETRIC ISOTOPE-RATIO MEASUREMENTS

The recommendations below are presented so that individuals engaged in mass spectrometric isotope-ratio measurements can ensure that their publications include all of the information needed for a systematic evaluation of isotope-ratio-measurement uncertainty by CIAAW. The primary task of CIAAW is the biennial evaluation of published isotope-ratio measurements to identify elements whose standard atomic weight and uncertainty can be revised. The exclusive basis of these CIAAW decisions is the information that is provided in the original peer-reviewed publication describing the measurement. CIAAW and SIAM use only peer-reviewed published information. Mass spectrometric measurements are a complex task and are subject both to systematic and statistical errors in the measurement itself and in the various steps involved in the preparation of the measurement and the evaluation of measurement data. To fulfill its task, CIAAW needs to assess the quality of a published measurement, specifically by (a) evaluating possible sources of errors in the measurements and their magnitude and (b) evaluating if sources of error have been properly considered by the authors and propagated to the primary measurement result, i.e., the published isotope ratios. From the reported isotope ratios, isotopic abundances can be calculated and multiplied with the nuclide masses to obtain the atomic weight of the element in the analyzed sample. Based on this assessment, SIAM/CIAAW makes a judgment in how far reported uncertainties in the measurement need to be expanded in order to ensure that the "true" value of the atomic weight of the element in the analyzed sample(s) lies within the margins set by the final uncertainty statement published together with the standard atomic weight. For elements showing substantial natural variations in isotopic abundances, this uncertainty may have to be expanded beyond purely measurement-related uncertainties in the underlying isotope-amount ratios or isotopic abundances.

From this, it becomes apparent that the successful work of CIAAW depends largely on the availability of all information that is necessary for a comprehensive evaluation of a reported isotope-amount-ratio measurement in the literature. Sources of errors in isotope-amount-ratio measurements can be random or systematic. Authors normally account for random errors, but some systematic errors may be unaccounted for when looking at the data from a CIAAW perspective. This might be because sources of error were unimportant for the topic of the publication or sources of error were overlooked. For the Commission, a proper uncertainty evaluation considering both random and potential systematic errors is important for transparency and consistency of its published data. Potential systematic errors in the measurement will be accounted for by expanding the uncertainty in the measurement symmetrically. From the corrected isotope-amount ratios, both isotope abundances and atomic weights can be calculated.

An evaluation of isotope abundance data by the Commission generally proceeds as follows:

1. Potential best measurement publications are selected by SIAM.
2. SIAM makes a review and extracts measurement results following these guidelines. The published isotope-amount ratios and their associated uncertainties are transferred to an element evaluation form. To allow combination with other data, the reported uncertainties must be converted to standard uncertainties. To convert to standard uncertainties, SIAM follows the recommendations in the JCGM *Guide to the Expression of Uncertainty in Measurement* (GUM) [41]. The re-

ported isotope-amount ratios are evaluated and, if needed, uncertainties are expanded to cover possible systematic errors in the measurements. Reported values are corrected only if there is sufficient information in the publication for reliable estimation of systematic offsets. Details on the mathematical approach for expanding uncertainties of published isotope ratios are given below.

3. After calculation using GUM Workbench software, isotope-amount ratios, molar fractions, and the atomic weight with their (expanded) standard uncertainties are exported back to the element database.

For evaluating uncertainties of published isotope-amount ratios, the following sources of systematic errors, at a minimum, should be considered where x represents possible systematic offsets and k represents the corresponding correction factor:

1.	System linearity	x_l	k_l
2.	Baseline correction	x_b	k_b
3.	Isobaric interferences	x_i	k_i
4.	Instrumental fractionation	x_f	k_f
5.	Sample preparation	x_p	k_p

For the correction of systematic offsets, a correction factor is introduced that carries an uncertainty $k = x \pm u(x)$ where k is the correction factor for a potential systematic error and $u(x)$ is the uncertainty of the correction factor. Both k and $u(x)$ may be different for individual isotope ratios of an element. Unless it is possible to calculate or estimate a reliable systematic offset from published isotope ratios, x will be set to 1. When considering the above sources of uncertainty, the corrected isotope-number ratio R can be expressed as

$$R = r \cdot k_l \cdot k_b \cdot k_i \cdot k_f \cdot k_p$$

where r is the published isotope-amount ratio.

Applying the laws of error propagation, the relative uncertainty of R, $(u(R)/R)$, is given by

$$\frac{u(R)}{R} = \sqrt{\left(\frac{u(r)}{r}\right)^2 + \left(\frac{u(k_l)}{k_l}\right)^2 + \left(\frac{u(k_b)}{k_b}\right)^2 + \left(\frac{u(k_i)}{k_i}\right)^2 + \left(\frac{u(k_f)}{k_f}\right)^2 + \left(\frac{u(k_p)}{k_p}\right)^2}$$

Because no reported isotope-ratio value will be revised unless the magnitude of a systematic offset in the data can be assessed from published information, k always equals 1.

The Commission considers the following systematic offsets when reviewing publications. As far as possible, the measurement modes or measurement conditions are listed in descending order in relation to the possible magnitude of the offset.

1. Offsets due to system nonlinearity (k_l)
   - fully calibrated measurement (including a linearity check)
   - Faraday cup(s) for ion detection
     - single collector
     - multicollector (use of a virtual amplifier system; correction for differences in cup efficiency; use of gain factors for each individual cup)
   - secondary electron multiplier(s) for ion detection (single ion counting, continuous mode)
2. Offsets due to baseline effects (k_b)
   - detector system (Faraday cup(s) or secondary electron multipliers)
   - measurement mode (on peak/between peaks, closed valve/open valve, between scans/blocks/measurements)

3. Offsets due to isobaric interferences (k_i)
   - correction of known/identified isobaric interferences (TIMS, ICP-MS)
   - using a measured isotope-amount ratio to consider natural or instrumental fractionation effects
   - use of a tabulated isotope-amount ratio
   - ICP-MS measurements
   - demonstrated absence of isobaric interferences (three-isotope plots)
   - assessment for presence of uncorrected isobaric interferences
     - instrument type (high resolution, collision cell, low resolution, etc.)
     - separation of element from sample matrix
     - direct measurement of samples in complex matrix
4. Offsets due to instrumental fractionation effects (k_f)
   - fully calibrated measurement
   - total evaporation method (TIMS)
   - no normalization applied
   - internal normalization (TIMS, ICP-MS)
     - using some (one or more) self-determined, calibrated isotope-ratio measurements
     - using a published isotope ratio from the literature
   - external normalization (ICP-MS)
     - by standard/sample bracketing (using a certified isotopic reference material; using an uncertified reference material; using matrix-matched samples/standards)
   - by normalization to a second, spiked element (using a certified isotopic reference material; using an uncertified consensus reference material; validity of correction technique established; as part of the publication/survey; by adopting findings from other authors)
5. Offsets due to fractionation effects during sample preparation (k_p)
   - separation of an element from the sample matrix
   - monitored by parallel processing of a standard (using a certified isotopic reference material; using a reference material having a consensus value)
   - separation procedure and separation yield were checked beforehand
   - analysis of shelf reagent/standard without matrix separation

MEMBERSHIP OF SPONSORING BODIES

Membership of the Inorganic Chemistry Division Committee for the period 2008–2009 was as follows:

***President*:** K. Tatsumi (Japan); ***Past President*:** A. R. West (UK); ***Secretary*:** L. V. Interrante (USA); ***Vice President*:** R. D. Loss (Australia); ***Titular Members*:** T. B. Coplen (USA); T. Ding (China/Beijing); J. Garcia-Martinez (Spain); M. Leskelä (Finland); L. A. Oro (Spain); J. Reedijk (Netherlands); M. P. Suh (Korea); ***Associate Members*:** A. V. Chadwick (UK); M. Drábik (Slovakia); N. E. Holden (USA); S. Mathur (Germany); K. Sakai (Japan); J. Takats (Canada); ***National Representatives*:** T. V. Basova (Russia); A. Bologna Alles (Uruguay); R. Gonfiantini (Italy); P. Karen (Norway); L.-K. Liu (China/Taipei); L. R. Ohrström (Sweden).

Membership of the Commission on Isotopic Abundances and Atomic Weights for the period 2008–2009 was as follows:

***Chair*:** T. P. Ding (China); ***Secretary*:** M. E. Wieser (Canada); ***Titular Members*:** M. Berglund (Belgium); T. Walczyk (Switzerland); S. Yoneda (Japan); ***Associate Members*:** R. Gonfiantini (Italy); M. Gröning (Austria); H. Hidaka (Japan); X.-K. Zhu (China); ***National Representatives*:** J. K. Böhlke (USA); P. De Bièvre (Belgium); J. de Laeter (Australia).

Membership of the Task Group on Evaluated Published Isotope Ratio Data (2005–2007) was as follows:

Chair: M. Berglund (Belgium); ***Members*****:** T. B. Coplen (USA); P. De Bièvre (Belgium); J. R. de Laeter (Australia); T. Ding (China/Beijing); R. Gonfiantini (Italy); M. Gröning (Austria); N. E. Holden (USA); R. D. Loss (Australia); K. J. R. Rosman (Australia, deceased); E. Roth (France, deceased); T. R. Walczyk (Switzerland); M. Wieser (Canada); M.-t. Zhao (China/Beijing); X. Zhu (China/Beijing).

The Commission on Isotopic Abundances and Atomic Weights notes the death of two former members of the Commission. Harry J. Svec, 24 June 1918 to 28 November 2006, developed the isotopic reference material used for lithium measurements called L-Svec. Harry was an Associate Member of the Commission from 1967 to 1971. Aaldert H. Wapstra, 24 April 1923 to 2 December 2006, published, on behalf of IUPAP, the Atomic Mass Table that is used to calculate the atomic weight values of the chemical elements for the last half-century. Aaldert was a Titular Member, as well as an Associate Member, of the Commission from 1963 to 1979.

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