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ATOMIC WEIGHTS OF THE ELEMENTS 2005

(IUPAC TECHNICAL REPORT)

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Atomic weights of the elements 2005

(IUPAC Technical Report)

Abstract: The latest evaluation of atomic weight determinations and other cognate data has warranted 16 changes for the standard atomic weights of the elements, A_r(E), from those published previously in the 2001 Table of Atomic Weights. The revised standard atomic weights are as follows: A_r(Al) = 26.981 5386(8), A_r(Bi) = 208.980 40(1), A_r(Cs) = 132.905 4519(2), A_r(Co) = 58.933 195(5), A_r(Au) = 196.966 569(4), A_r(La) = 138.905 47(7), A_r(Mn) = 54.938 045(5), A_r(Nd) = 144.242(3), A_r(P) = 30.973 762(2), A_r(Pt) = 195.084(9), A_r(Sm) = 150.36(2), A_r(Sc) = 44.955 912(6), A_r(Na) = 22.989 769 28(2), A_r(Ta) = 180.947 88(2), A_r(Tb) = 158.925 35(2), A_r(Th) = 232.038 06(2). A recommendation is made that δ^{13}C values of all carbon-bearing materials be measured and expressed relative to Vienna Pee Dee Belemnite (VPDB) on a scale normalized by assigning consensus values of –46.6 ‰ to L-SVEC lithium carbonate and +1.95 ‰ to NBS 19 calcium carbonate.

Keywords: IUPAC Inorganic Chemistry Division; atomic weights; elements; isotopic abundance; mononuclidic; polynuclidic.

INTRODUCTION

The Commission on Isotopic Abundances and Atomic Weights (CIAAW) met under the chairmanship of Prof. T. P. Ding from 11 to 13 August 2005, during the 43rd IUPAC General Assembly in Beijing, China. The Commission decided to publish the report "Atomic Weights of the Elements 2005" 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 atomic weights reported in Tables 1 and 2 are for atoms in their nuclear and electronic ground states.

The atomic weight, A_r(E), of element E can be determined from the knowledge of the isotopic abundances and corresponding atomic masses of the nuclides of that element. At the 2005 meeting, the Commission reviewed the literature from the four years since the last compilation of atomic weights and isotopic abundances in 2001 [1,2] and evaluated the published data on atomic weights and isotopic compositions on an element-by-element basis. The Commission used the atomic mass evaluations of 2003 [3] in this new compilation.

The Commission periodically reviews the history of the 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 measurements in order to improve the atomic weights of a number of elements, which are still not known to a satisfactory level of accuracy. However, for many elements, the limited accuracy of measurements is overshadowed by terrestrial variability, which is included in the tabulated uncertainty of the atomic weights.

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 [5]. 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 this case, the atomic weights are considered to be constants of nature, and periodic changes in the values and uncertainties 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 values 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 atomic weights are most materials with deliberately altered isotopic compositions, extraterrestrial materials, and anomalous occurrences such as the Oklo natural nuclear reactor.

Variations in the relative amounts of isotopes of the elements in different materials commonly can be measured with greater precision than 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 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 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 for which the standard atomic weight and its uncertainty 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 $A_r(\mathrm{E})$ or its uncertainty, $U[A_r(\mathrm{E})]$ (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 Coplen and Peiser [6]. Values before the formation of the International Committee on Atomic Weights in 1900 come from F. W. Clarke [7].

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" [8]. 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 and reviewed. The 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 2005.
[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				
Name	Symbol	Number	Atomic weight	Footnotes
actinium*	Ac	89		
aluminium (aluminum)	Al	13	26.981 5386(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 4519(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
chromium	Cr	24	51.9961(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)	

(*continues on next page*)

Table 1 (*Continued*).

Alphabetical order in English				
Name	Symbol	Number	Atomic weight	Footnotes
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	174.967(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	95.94(2)	g
neodymium	Nd	60	144.242(3)	g
neon	Ne	10	20.1797(6)	g m
neptunium*	Np	93		
nickel	Ni	28	58.6934(2)	
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
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)	

(*continues on next page*)

Table 1 (*Continued*).

Alphabetical order in English				
Name	Symbol	Number	Atomic weight	Footnotes
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	173.04(3)	g
yttrium	Y	39	88.905 85(2)	
zinc	Zn	30	65.409(4)	
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 2005.
[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

Number	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)	
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(2)	
29	copper	Cu	63.546(3)	r
30	zinc	Zn	65.409(4)	
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)	

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number				
Number	Name	Symbol	Atomic weight	Footnotes
40	zirconium	Zr	91.224(2)	g
41	niobium	Nb	92.906 38(2)	
42	molybdenum	Mo	95.94(2)	g
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 4519(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)	
68	erbium	Er	167.259(3)	g
69	thulium	Tm	168.934 21(2)	
70	ytterbium	Yb	173.04(3)	g
71	lutetium	Lu	174.967(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*	Fr		

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number				
Number	Name	Symbol	Atomic weight	Footnotes
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		
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 amounts of isotopes of an element. The best measurement may be defined as a complete analysis of the isotope-amount 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 ratios, and data handling.

Criteria used to evaluate a "best measurement" include:

- The extent to which random and systematic effects 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 variations of isotope-amount ratios in Nature over the range of the masses of the isotopes in the material being analyzed.
- 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.

Following are brief descriptions of the changes in the Table of Standard Atomic Weights resulting from the Commission meeting in 2005. The Commission noted that, in addition to the mononuclidic elements, there are two additional elements, lanthanum and tantalum, for which the isotope-amount ratio measurement now has a lower uncertainty than the uncertainty on the masses in the atomic mass table [3]. The overall value of the uncertainty in the atomic weight value of these elements now have components, which are controlled by the uncertainty of atomic masses in these two elements.

Samarium

The Commission has changed the recommended value for the standard atomic weight of samarium to A_r(Sm) = 150.36(2) based on a new calibrated measurement by Chang et al. [9]. The Commission noted that although gravimetrically prepared mixtures of samarium isotopes were used for the calibration, there was no assessment of the linearity of the measurement system, which it took into consideration when arriving at the final uncertainty. Chang et al. [9] included measurements of five different samples from China, the United States, and Japan in their study and found no evidence of measurable variation. The previous value, A_r(Sm) = 150.36(3), recommended in 1979 [10] was based on measurements by Lugmair et al. [11]. Historical values of A_r(Sm) include [6]: 1894, 150.0; 1897, 150.26; 1900, 150.3; 1903, 150; 1905, 150.3; 1909, 150.4; 1925, 150.43; 1955, 150.30; 1969, 150.4(1); and 1979, 150.36(3).

Platinum

The Commission has changed the recommended value for the standard atomic weight of platinum to A_r(Pt) = 195.084(9), based on partially calibrated inductively coupled plasma mass spectrometric measurements of Briche et al. [12]. The previous value of A_r(Pt) = 195.078(2), adopted in 1995, was based on electron impact ionization of gaseous $Pt(PF_3)_4$ and measurement of Pt^+ ions in a mass spectrometer.

The earlier measurement (evaluated in 1995) was not published in a peer-reviewed journal. This value was adopted erroneously in 1995 because it did not meet the minimum standards for the Commission to change an atomic weight value. Publication of analytical data in a refereed journal is the precondition for the Commission to evaluate the atomic weight. Historical values of A_r(Pt) include [6]: 1882, 194.87; 1894, 195; 1896, 194.89; 1900, 194.9; 1903, 194.8; 1909, 195.0; 1911, 195.2; 1925, 195.23; 1955, 195.09; 1969, 195.09(3); 1979, 195.08(3); and 1995, 195.078(2).

Tantalum

The Commission has changed the recommended value for the standard atomic weight of tantalum to A_r(Ta) = 180.947 875(8) based on a recent measurement by de Laeter and Bukilic [13]. The linearity of the mass spectrometer was verified using a certified potassium reference material (NIST 985), and instrumental fractionation of the amounts of isotopes of tantalum was corrected using a certified rhenium isotopic reference material (NIST 989). The uncertainties in the atomic weight were increased to reflect that this was not a fully calibrated measurement. Due to the low abundance of ^{180}Ta, 97 % of the uncertainty of the recommended value for A_r(Ta) comes from the uncertainty in the nuclide mass of ^{181}Ta. Historical values of A_r(Ta) include [6]: 1882, 182.56; 1894, 182.6; 1897, 182.84; 1900, 182.8; 1903, 183; 1907, 181.0; 1910, 181.5; 1931, 181.4; 1936, 180.88; 1953, 180.89; 1961, 180.948; 1969, 180.9479(3); and 1979, 180.9479(1).

Neodymium

The Commission has changed the recommended value for the standard atomic weight of neodymium to A_r(Nd) = 144.242(3) based on a new calibrated measurement by Zhao et al. [14]. This measurement provides a significant improvement in uncertainty from 0.03 to 0.003. Zhao et al. [14] included measurements of seven different samples from China, the United States, and Japan in their study and found no evidence for measurable variations. The previous value, A_r(Nd) = 144.24(3), was based on the average of isotope amount measurements of Inghram et al. [15] and Walker and Thode [16] arriving at a value of 144.24 that was adopted in 1961 [17] and an evaluated uncertainty was included in 1969 [18]. Historical values of A_r(Nd) include [6]: 1894, 140.5; 1897, 140.80; 1899, 143.6; 1909, 144.3; 1925, 144.27; 1961, 144.24(3); and 1969, 144.24(3).

Lanthanum

The Commission has changed the recommended value and uncertainty for the standard atomic weight of lanthanum to A_r(La) = 138.905 47(7) based on new isotope amount data of de Laeter and Bukilic [19] and the data from the 2003 Atomic Mass Table by Audi et al. [3]. The previous atomic weight value was A_r(La) = 138.9055(2), which was based on the average of the isotope amount data of Inghram et al. [15] and White [20]. Historical values of A_r(La) include [6]: 1882, 138.84; 1894, 138.2; 1896, 138.6; 1897, 138.64; 1900, 138.6; 1903, 138.9; 1909, 139.0; 1925, 138.90; 1933, 138.92; 1961, 138.91; 1969, 138.9055(3); and 1985, 138.9055(2).

MONONUCLIDIC ELEMENTS (ALUMINIUM, BISMUTH, CAESIUM, COBALT, GOLD, MANGANESE, PHOSPHORUS, SCANDIUM, SODIUM, TERBIUM, AND THORIUM)

The atomic weights for the mononuclidic elements are based on atomic mass data derived from physical measurements. The uncertainty values assigned by the Commission to the atomic weights of the mononuclidic elements are the atomic mass uncertainties expanded by a factor of six and then rounded up to the next single digit. Updated atomic weights are provided for those elements for which there have been improvements in the measurement precision of the atomic mass values as reported in [3] since the previous evaluation [1].

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.

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 for radioactive materials with a variety of isotopic compositions. Nuclidic mass values have been taken from the 2003 Atomic Mass Table [3]. Some of these half-lives have already been documented [21–24].

Table 3 Relative atomic masses and half-lives of selected radionuclides.
[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	$4.2(2) \times 10^6$	a
			98	97.9072	$6.6(1.0) \times 10^6$	a
			99	98.9063	$2.1(3) \times 10^5$	a
61	promethium	Pm	145	144.9127	17.7(4)	a
			147	146.9151	2.623(3)	a
84	polonium	Po	209	208.9824	102(5)	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	211	210.9906	14.6(2)	h
			220	220.0114	55.6(1)	s
			222	222.0176	3.823(4)	d
87	francium	Fr	223	223.0197	22.0(1)	min
88	radium	Ra	223	223.0185	11.43(1)	d
			224	224.0202	3.66(2)	d
			226	226.0254	1599(4)	a
			228	228.0311	5.76(3)	a
89	actinium	Ac	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
91	protactinium	Pa	231	231.0359	$3.25(1) \times 10^4$	a
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

(*continues on next page*)

Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
93	neptunium	Np	237	237.0482	$2.14(1) \times 10^6$	a
			239	239.0529	2.355(6)	d
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
100	fermium	Fm	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	259	259.1010	58(5)	min
103	lawrencium	Lr	262	262.1096	3.6(3)	h
104	rutherfordium	Rf	267	267.1215	1.3[a]	min
105	dubnium	Db	268	268.1255	~0.7[a]	d
106	seaborgium	Sg	271	271.1335	~21[a]	s
107	bohrium	Bh	272	272.1380	~10[a]	s
108	hassium	Hs	277	277.150	16.5[a,b]	min
109	meitnerium	Mt	276	276.1512	0.7[a,b]	s
110	darmstadtium	Ds	281	281.162	~9.6[a,b]	s
111	roentgenium	Rg	280	280.1645	~3.6[a,b]	s
112	ununbium	Uub	285	285.174	~34[a,b]	s
113	ununtrium	Uut	284	284.178	~0.5[a,b]	s
114	ununquadium	Uuq	289	289.189	~2.7[a,b]	s
115	ununpentium	Uup	288	288.192	~87[a,b] $\times 10^{-3}$	s
116	ununhexium	Uuh	293		~0.05[a,b]	s
118	ununoctium	Uuo	294		~1.8[a,b] $\times 10^{-3}$	s

[a]The uncertainties of these elements are asymmetric.
[b]The value given is determined only from a few decays.

RECOMMENDATION ON THE REPORTING OF δ^{13}C MEASUREMENTS

Differences in measured isotope amount ratios of stable carbon isotopes ($^{13}C/^{12}C$), commonly called δ^{13}C values, are used to understand processes in oceanography, atmospheric sciences, biology, paleoclimatology, geology, environmental sciences, and food and drug authentication. Progress in these fields requires smaller measurement uncertainties to be achieved. Advances in instrumentation enable increasingly precise measurements. Nevertheless, laboratories measuring the same specimen often disagree by 10 times their reported "uncertainty" of measurement [25,26] and agreement has not improved substantially in the last two decades except in a few cases [27].

Recognizing that two-point calibrations of the δ^{2}H and δ^{18}O scales substantially improved the agreement among laboratories [28], the IAEA convened a consultants meeting in 2004 to calibrate internationally distributed stable carbon isotopic reference materials and to recommend another reference material for two-point normalization of the δ^{13}C scale. Dr. M. Gröning reported in Beijing on the outcome of the work of the consultants.

Four laboratories (Centrum voor Isotopen Onderzoek (CIO), Groningen, Netherlands; Max-Planck-Institute for Biogeochemistry (MPI), Jena, Germany; UFZ Umweltforschungszentrum Leipzig-Halle, Leipzig, Germany; U.S. Geological Survey (USGS), Reston, Virginia, USA) utilized state-of-the-art analysis with continuous-flow elemental analyzer (EA) techniques [29] to analyze selected organic and inorganic carbon isotopic reference materials. NBS 19 calcium carbonate was adopted as the reference material for anchoring at high ^{13}C content and was assigned the value +1.95 ‰ relative to Vienna Pee Dee Belemnite (VPDB) following recommendations of the IAEA and IUPAC [30,31]. L-SVEC lithium carbonate (NIST RM 8545) was selected as the low-^{13}C content scale anchor because EA δ^{13}C values of amounts as small as 0.3 mg are statistically identical and carbonates are easily prepared for analysis using H_3PO_4. L-SVEC was assigned a δ^{13}C consensus value of –46.6 ‰ based on high accuracy measurements [32].

From a total of 1055 δ^{13}C measurements by four laboratories on 13 materials, recommended δ^{13}C values were determined by a multivariate Bayesian analysis [33]. Recommended δ^{13}C values (on a scale anchored by L-SVEC equals –46.6 ‰) were determined for three CO_2 gases (NIST RM 8562, RM 8563, and RM 8564) and three calcium carbonate reference materials (IAEA-CO-1, IAEA-CO-8, and NBS 18) because high-quality data were available [27,32]. Uncertainties of reference material values on this scale are improved by factors up to two or more (Fig. 1) and the values of some have been notably shifted—the δ^{13}C of NBS 22 oil is –30.03 ‰, which is substantially more negative than the value reported by Gonfiantini et al. [34] of –29.74 ‰, but it is in line with the Qi et al. [29] value of –29.99 ‰ (normalized to L-SVEC value of –46.6 ‰).

The Commission accepted the recommendations of this IAEA panel that δ^{13}C values of all carbon-bearing materials be measured and expressed relative to VPDB on a scale normalized by assigning consensus values of –46.6 ‰ to L-SVEC lithium carbonate and +1.95 ‰ to NBS 19 calcium carbonate, and authors should clearly state so in their reports. Authors are encouraged to report their measurement results for δ^{13}C values of NBS 22 oil, USGS 41 L-glutamic acid, IAEA-CH-6 sucrose, or other internationally distributed reference materials, as appropriate for the measurement method concerned. Adoption of these guidelines should enable laboratories worldwide measuring the same sample to report δ^{13}C values that agree with one another to within measurement uncertainty.

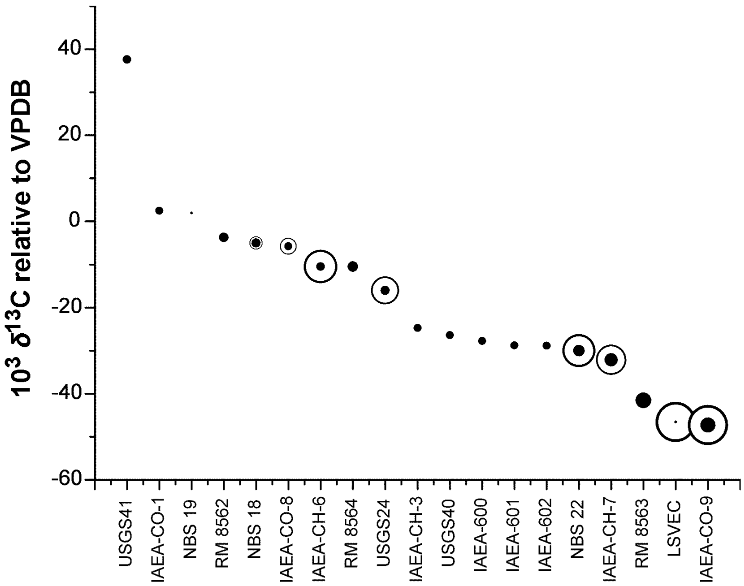

Fig. 1 Improvement in combined standard uncertainty for $\delta^{13}C$ reference materials compared with previously assessed uncertainty. Sizes of solid points indicate newly estimated uncertainties (largest solid circle is equivalent to an uncertainty of 0.06 ‰), diameter of open circles (older materials only) indicate their previously estimated uncertainties (largest open circle is equivalent to an uncertainty of 0.15 ‰). By consensus, $\delta^{13}C$ values of NBS 19 and L-SVEC have no associated uncertainty on the normalized scale.

OBITUARIES

It was noted with sadness that two former members of the Commission, Mr. H. Steffen Peiser and Dr. John W. Gramlich, had passed away. Mr. Peiser served as a member of the Commission from 1967 to 1985, as a Secretary of the Commission from 1969 to 1975 and later as a U.S. National Representative. He also served as a member of the Commission's Subcommittee for the Assessment of Isotopic Composition (SAIC), the Subcommittee on Natural Isotopic Fractionation (SNIF), and the Subcommittee for Isotopic Abundance Measurements (SIAM). Dr. Gramlich served as a member of the Commission from 1985 to 1997 and also of SIAM.

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