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IUPAC Technical Report

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Isotopic compositions of the elements 2013 (IUPAC Technical Report)

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Abstract: The Commission on Isotopic Abundances and Atomic Weights (ciaaw.org) of the International Union of Pure and Applied Chemistry (iupac.org) has revised the Table of Isotopic Compositions of the Elements (TICE). The update involved a critical evaluation of the recent published literature. The new TICE 2013 includes evaluated data from the "best measurement" of the isotopic abundances in a single sample, along with a set of representative isotopic abundances and uncertainties that accommodate known variations in normal terrestrial materials.

Keywords: atomic weight; ciaaw.org; critical evaluation; elements; isotopes; isotopic abundance; IUPAC Technical Report; periodic table.

1 Introduction

The Commission on Isotopic Abundances and Atomic Weights (hereafter called the Commission or CIAAW) of the International Union of Pure and Applied Chemistry (IUPAC) has provided regular assessments of the standard atomic weights and isotopic compositions of the elements. The first Table of Isotopic Compositions was published by the Commission in 1931, based on the work of Francis W. Aston, and it included only seven elements [1]. Since then, CIAAW has evaluated the isotopic compositions of all elements having a tabulated standard atomic weight by examining the most accurate and precise isotopic-abundance measurements in selected samples through its Subcommittee for Isotopic Abundance Measurements (SIAM), its predecessor

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Subcommittee on Assessment of Isotopic Composition (SAIC), and by compiling evidence for known variations of the isotopic abundances of the elements in normal materials through its former Subcommittee on Natural Isotopic Fractionation (SNIF). By a "normal material" CIAAW means a material from a terrestrial source that satisfies the following criterion [2]:

> "The material is a reasonably possible source for this element or its compounds in commerce, for industry or science; the material is not itself studied for some extraordinary anomaly and its isotopic composition has not been modified significantly in a geologically brief period."

The results of these investigations are important for a number of reasons. The evaluated best measurements indicate the state of the metrology of isotope-abundance measurements, the best measurements provide benchmark data for isotopic reference materials, and the combination of best measurements and documented variations serve as the basis for the standard atomic weights of the elements.

The current Table of the Isotopic Compositions of the Elements, TICE 2013, was produced by CIAAW to accompany the 2013 Table of Standard Atomic Weights of the Elements (TSAW 2013) [3]. The previous table of the isotopic compositions of the elements, TICE 2009, was published in 2011 [4], following CIAAW deliberations in 2009. TICE 2013 is intended to include data for normal materials and does not include published values for meteoritic or other extraterrestrial materials. Additional supporting data and background information can be found in the reports of de Laeter *et al.* [5] and Coplen *et al.* [6, 7].

2 Consistency with the atomic weights

Care has been taken to ensure that the representative isotopic abundances and uncertainties for all elements are consistent with the corresponding standard atomic weights and their uncertainties, including the twelve elements whose standard atomic-weight values are given as an interval. Isotope-amount ratios, isotopic abundances (also called isotope-amount fractions and atom fractions [8]), and the atomic weight of an element are related quantities. For this reason, the information given in the Table of Standard Atomic Weights and in the Table of Isotopic Compositions (Column 9) must be consistent with one another, as stated by CIAAW in 1983 [2]. Consider, for example, the standard atomic weight of copper, $A_r(\mathrm{Cu}) = 63.546(3)$, and its representative isotopic composition, $x(^{63}\mathrm{Cu}) = 0.6915(15)$ and $x(^{65}\mathrm{Cu}) = 0.3085(15)$. The atomic-weight value of 63.546 corresponds to isotopic abundances 0.6915 and 0.3085. Likewise, the atomic-weight value of, for example, $63.546 + 0.003$ corresponds to isotopic abundances $0.6915 - 0.0015$ and $0.3085 + 0.0015$. In practice, however, matching the standard atomic weights, isotopic compositions and their uncertainties with the corresponding isotope amount ratios and their uncertainties is not an easy task considering that, over the last fifty years, the input data of these tables have been evaluated while statistical data treatment and other methods have changed. Nevertheless, care has been taken in this report to ensure that the representative isotopic abundances and their uncertainties for all elements (Column 9) are consistent with the standard atomic weights and their uncertainties.

3 Isotopic-abundance intervals for elements with intervals as standard atomic weights

Since 2009, standard atomic weights of selected elements are expressed using the interval notation to reflect the variability of atomic-weight values in normal materials [9] and to emphasize that atomic-weight values of these elements are not constants of nature [10, 11]. In keeping with these interval values of standard atomic weights, intervals for representative isotopic abundances of these elements are given in Column 9 of the Table of Isotopic Compositions of the Elements (Table 1). For elements with only two stable isotopes (H, Li, B, C, N, Cl, Br, and Tl), the lower and upper bounds of the isotopic abundances listed in Column 9 will agree with the corresponding bounds of the standard atomic weight to within ±1 in the last digit quoted. For elements with more than two stable isotopes (O, Mg, Si, and S), the reported isotopic abundance variations are calculated from the standard atomic weights using standard mass-dependent fractionation models (see discussion page 2551 of [8]). The number of decimal digits in the isotopic-abundance intervals is determined in the same fashion as they are determined for the standard atomic weights. In particular, the number of decimal digits in the lower and upper bounds is determined so that the uncertainty in the last quoted digit is less than one.

4 Table of isotopic compositions

The Table of Isotopic Compositions of the Elements (Table 1) consists of nine columns, as explained below.
Column 1: Atomic number (Z) of the element.
Column 2: Symbol of the element.
Column 3: Mass number (A) of each isotope that can be found in normal materials.
Column 4: Interval of isotopic-abundance variation in normal materials. No data are given in this column unless an interval has been reliably established (see, *e.g.*, Coplen *et al.* [6, 7]). The interval given may not include those of certain exceptional samples, which are indicated with a "g" in Column 5. The isotopic abundance of each stable isotope is given as an isotopic-abundance interval with the symbol $[a, b]$ to denote the set of isotopic-abundance values in normal materials; thus, $a \leq$ isotopic abundance $\leq b$. The symbols a and b denote the lower and upper bounds of the interval $[a, b]$, respectively. For 12 elements having atomic-weight values that are intervals (H, Li, B, C, N, O, Mg, Si, S, Cl, Br, and Tl), figures of variations in isotopic abundances and atomic weights for selected materials are presented in TSAW 2013 [3].
Column 5: Annotations.

g geologically exceptional specimens are known in which the element has an isotopic composition outside the reported interval.

m modified isotopic compositions may be found in commercially available material that has been subjected to an undisclosed or inadvertent isotope fractionation. Substantial deviations from the listed isotopic compositions can occur (refers to Column 9).

r range in isotopic composition of normal terrestrial material prevents more precise values (for Column 9) to be given. The tabulated values should be applicable to any normal material.

Note that the annotations apply to all isotopes of a given element.

Column 6: The best measurement of isotopic abundances from a single terrestrial source. The values are reproduced or recalculated by CIAAW from the original literature and are sometimes adjusted for minor errors or reformatted for easier reading. The uncertainties on the last digits are given in parentheses. As they are not reported in a uniform manner in the literature, numerals 1, 2, or 3 indicate the coverage factor applied to the standard deviation (s), to the standard error (standard deviation of the mean, s_e), or to the combined uncertainty (u_c).

C is appended for a fully calibrated measurement when gravimetrically prepared isotope mixtures have been used to correct the underlying mass spectrometric measurement results for bias.

F is appended for a partially calibrated measurement when calibrated mixtures have been used to correct for measurement bias, but the measurement fails to fulfill all of the requirements of a "**C**" measurement.

N is appended for a non-calibrated measurement.

Users should be aware that a "best measurement" is not necessarily calibrated, nor is it necessarily free of systematic biases; it is just the best measurement available. Users seeking isotopic composition of unspecified natural sample should refer to Column 9.

Column 7: Reference for the best measurement in Column 6.
Column 8: Material that was used for the best measurement given in Column 6. An asterisk signifies that a substance is a recognized isotopic reference material [84]. The listed materials do not necessarily define the origin of the delta zero scale.

Table 1: Isotopic compositions of the elements 2013.

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
1	H	1	[0.999 72, 0.999 99]	m	0.999 844 26(5) 2*s* C	[12]	VSMOW*	[0.999 72, 0.999 99]
		2	[0.000 01, 0.000 28]		0.000 155 74(5)			[0.000 01, 0.000 28]
2	He	3	[4.6×10^{-10}, 0.000 041]	g, r	0.000 001 343(13) 1*s* C	[13]	Air*	0.000 002(2)
		4	[0.999 959, 1.000 000]		0.999 998 657(13)			0.999 998(2)
3	Li	6	[0.019, 0.078][a]	m	0.075 89(24) 2*s* C	[14]	IRMM-016*	[0.019, 0.078][a]
		7	[0.922, 0.981][a]		0.924 11(24)			[0.922, 0.981][a]
4	Be	9			1	[15]		1
5	B	10	[0.189, 0.204]	m	0.1982(2) 2*s* C	[16]	IRMM-011*	[0.189, 0.204]
		11	[0.796, 0.811]		0.8018(2)			[0.796, 0.811]
6	C	12	[0.9884, 0.9904]		0.988 922(28) n/a C	[17]	NBS 19*	[0.9884, 0.9904]
		13	[0.0096, 0.0116]		0.011 078(28)			[0.0096, 0.0116]
7	N	14	[0.995 78, 0.996 63]	m	0.996 337(4) n/a C	[18]	Air*	[0.995 78, 0.996 63]
		15	[0.003 37, 0.004 22]		0.003 663(4)			[0.003 37, 0.004 22]
8	O	16	[0.997 38, 0.997 76]	m	0.997 6206(9) 1*s* N	[19, 20]	VSMOW*	[0.997 38, 0.997 76]
		17	[0.000 367, 0.000 400]		0.000 3790(9)			[0.000 367, 0.000 400]
		18	[0.001 87, 0.002 22]		0.002 0004(5)			[0.001 87, 0.002 22]
9	F	19			1	[21]		1
10	Ne	20	[0.8847, 0.9051]	g, m	0.904 838(90) 1*s* C	[22]	Air*	0.9048(3)
		21	[0.0027, 0.0171]		0.002 696(5)			0.0027(1)
		22	[0.0920, 0.0996]		0.092 465(90)			0.0925(3)
11	Na	23			1	[23]		1
12	Mg	24	[0.7888, 0.7905]		0.789 51(12) 9u_c F	[24]	DSM-3*	[0.7888, 0.7905]
		25	[0.099 88, 0.100 34]		0.100 20(8)			[0.099 88, 0.100 34]
		26	[0.1096, 0.1109]		0.110 29(10)			[0.1096, 0.1109]
13	Al	27			1	[23]		1
14	Si	28	[0.921 91, 0.923 18]		0.922 2968(44) 2*s* C	[25]	WASO-17.2	[0.921 91, 0.923 18]
		29	[0.046 45, 0.046 99]		0.046 8316(32)			[0.046 45, 0.046 99]
		30	[0.030 37, 0.031 10]		0.030 8716(32)			[0.030 37, 0.031 10]
15	P	31			1	[15]		1
16	S	32	[0.9441, 0.9529]		0.950 4074(88) 2*s* C	[26]	IAEA-S-1*	[0.9441, 0.9529]
		33	[0.007 29, 0.007 97]		0.007 4869(60)			[0.007 29, 0.007 97]
		34	[0.0396, 0.0477]		0.041 9599(66)			[0.0396, 0.0477]
		36	[0.000 129, 0.000 187]		0.000 1458(9)			[0.000 129, 0.000 187]
17	Cl	35	[0.755, 0.761]	m	0.757 647(38) 2u_c C	[27]	NIST SRM 975*	[0.755, 0.761]
		37	[0.239, 0.245]		0.242 353(38)			[0.239, 0.245]
18	Ar	36		g, r	0.003 3361(35) 1*s* F	[28]	Air*	0.003 336(210)
		38			0.000 6289(12)			0.000 629(70)
		40			0.996 0350(42)			0.996 035(250)
19	K	39			0.932 581(29) 2*s* C	[29]	NIST SRM 985*	0.932 581(44)
		40			0.000 1167(4)			0.000 117(1)
		41			0.067 302(29)			0.067 302(44)
20	Ca	40	[0.969 33, 0.969 47]	g	0.969 41(6) 2*s* N	[30]	NIST SRM 915*	0.969 41(156)
		42	[0.006 46, 0.006 48]		0.006 47(3)			0.006 47(23)
		43	[0.001 35, 0.001 35]		0.001 35(2)			0.001 35(10)
		44	[0.020 82, 0.020 92]		0.020 86(4)			0.020 86(110)
		46	[0.000 04, 0.000 04]		0.000 04(1)			0.000 04(3)
		48	[0.001 86, 0.001 88]		0.001 87(1)			0.001 87(21)
21	Sc	45			1	[31]		1
22	Ti	46			0.082 49(21) 2*s* C	[32]	TiO_2	0.0825(3)
		47			0.074 37(14)			0.0744(2)

Table 1 (continued)

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
		48			0.737 20(22)			0.7372(3)
		49			0.054 09(10)			0.0541(2)
		50			0.051 85(13)			0.0518(2)
23	V	50	[0.002 487, 0.002 502]		0.002 497(6) 1*s* F	[33]	Lead vanadate	0.002 50(10)
		51	[0.997 498, 0.997 513]		0.997 503(6)			0.997 50(10)
24	Cr	50	[0.042 94, 0.043 45]		0.043 452(85) 2*s* C	[34]	NIST SRM 979*	0.043 45(13)
		52	[0.837 62, 0.837 90]		0.837 895(117)			0.837 89(18)
		53	[0.095 01, 0.095 53]		0.095 006(110)			0.095 01(17)
		54	[0.023 65, 0.023 91]		0.023 647(48)			0.023 65(7)
25	Mn	55			1	[15]		1
26	Fe	54	[0.058 37, 0.058 61]		0.058 450(230) 2*s* C	[35]	IRMM-014*	0.058 45(105)
		56	[0.917 42, 0.917 60]		0.917 540(240)			0.917 54(106)
		57	[0.021 16, 0.021 21]		0.021 191(65)			0.021 19(29)
		58	[0.002 81, 0.002 82]		0.002 819(27)			0.002 82(12)
27	Co	59			1	[15]		1
28	Ni	58		r	0.680 769(59) 2*s* C	[36]	NIST SRM 986*	0.680 769(190)
		60			0.262 231(51)			0.262 231(150)
		61			0.011 399(4)			0.011 399(13)
		62			0.036 345(11)			0.036 345(40)
		64			0.009 256(6)			0.009 256(19)
29	Cu	63	[0.689 83, 0.693 38]	r	0.691 74(20) 2*s* C	[37]	NIST SRM 976*	0.6915(15)
		65	[0.306 62, 0.310 17]		0.308 26(20)			0.3085(15)
30	Zn	64		r	0.491 704(83) 2*s* C	[38]	IRMM-3702*	0.4917(75)
		66			0.277 306(110)			0.2773(98)
		67			0.040 401(18)			0.0404(16)
		68			0.184 483(69)			0.1845(63)
		70			0.006 106(11)			0.0061(10)
31	Ga	69			0.601 079(62) 2*s* C	[39]	NIST SRM 994*	0.601 08(50)
		71			0.398 921(62)			0.398 92(50)
32	Ge	70			0.205 26(46) $2u_c$ F	[40]	Ge metal	0.2052(19)
		72			0.274 46(15)			0.2745(15)
		73			0.077 60(25)			0.0776(8)
		74			0.365 23(63)			0.3652(12)
		76			0.077 45(35)			0.0775(12)
33	As	75			1	[15]		1
34	Se	74		r	0.008 63(3) $2u_c$ F	[41]	NIST SRM 3149*	0.0086(3)
		76			0.092 20(6)			0.0923(7)
		77			0.075 94(4)			0.0760(7)
		78			0.236 85(14)			0.2369(22)
		80			0.498 13(16)			0.4980(36)
		82			0.088 25(8)			0.0882(15)
35	Br	79	[0.505, 0.508]		0.506 86(26) 2*s* C	[42]	NIST SRM 977*	[0.505, 0.508]
		81	[0.492, 0.495]		0.493 14(26)			[0.492, 0.495]
36	Kr	78		g, m	0.003 5518(32) 2*s* C	[43]	IRMM-2030* (Air)	0.003 55(3)
		80			0.022 8560(96)			0.022 86(10)
		82			0.115 930(62)			0.115 93(31)
		83			0.114 996(58)			0.115 00(19)
		84			0.569 877(58)			0.569 87(15)
		86			0.172 790(32)			0.172 79(41)
37	Rb	85		g	0.721 654(132) 2*s* C	[44]	NIST SRM 984*	0.7217(2)
		87			0.278 346(132)			0.2783(2)

Table 1 (continued)

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
38	Sr	84	[0.0055, 0.0058]	g, r	0.005 574(16) 2*s* C	[45]	NIST SRM 987*	0.0056(2)
		86	[0.0975, 0.0999]		0.098 566(34)			0.0986(20)
		87	[0.0694, 0.0714]		0.070 015(26)			0.0700(20)
		88	[0.8229, 0.8275]		0.825 845(66)			0.8258(35)
39	Y	89			1	[46]		1
40	Zr	90		g	0.514 52(9) 2*s* N	[47]	–	0.5145(4)
		91			0.112 23(12)			0.1122(5)
		92			0.171 46(7)			0.1715(3)
		94			0.173 80(12)			0.1738(4)
		96			0.027 99(5)			0.0280(2)
41	Nb	93			1	[23]		1
42	Mo	92		g	0.146 49(17) 1u_c F	[48]	NIST SRM 3134*	0.146 49(106)
		94			0.091 87(5)			0.091 87(33)
		95			0.158 73(5)			0.158 73(30)
		96			0.166 73(2)			0.166 73(8)
		97			0.095 82(3)			0.095 82(15)
		98			0.242 92(14)			0.242 92(80)
		100			0.097 44(10)			0.097 44(65)
43	Tc	–			–			–
44	Ru	96		g	0.055 420(1) 1*s* N	[49]	–	0.0554(14)
		98			0.018 688(2)			0.0187(3)
		99			0.127 579(6)			0.1276(14)
		100			0.125 985(4)			0.1260(7)
		101			0.170 600(10)			0.1706(2)
		102			0.315 519(11)			0.3155(14)
		104			0.186 210(11)			0.1862(27)
45	Rh	103			1	[15]		1
46	Pd	102		g	0.0102(1) 2*s* C	[50]	Pd wire	0.0102(1)
		104			0.1114(5)			0.1114(8)
		105			0.2233(5)			0.2233(8)
		106			0.2733(2)			0.2733(3)
		108			0.2646(6)			0.2646(9)
		110			0.1172(6)			0.1172(9)
47	Ag	107		g	0.518 392(51) 2*s* C	[51]	NIST SRM 978*	0.518 39(8)
		109			0.481 608(51)			0.481 61(8)
48	Cd	106		g	0.012 49(5) 2u_c C	[52]	BAM Cd-I012*	0.012 45(22)
		108			0.008 90(2)			0.008 88(11)
		110			0.124 85(14)			0.124 70(61)
		111			0.128 04(8)			0.127 95(12)
		112			0.241 17(3)			0.241 09(7)
		113			0.122 25(1)			0.122 27(7)
		114			0.287 29(18)			0.287 54(81)
		116			0.075 01(12)			0.075 12(54)
49	In	113			0.042 81(17) 2u_c F	[53]	JMC In	0.042 81(52)
		115			0.957 19(17)			0.957 19(52)
50	Sn	112		g	0.009 73(3) 1*s* C	[54, 55]	Sn metal	0.0097(1)
		114			0.006 59(3)			0.0066(1)
		115			0.003 39(3)			0.0034(1)
		116			0.145 36(31)			0.1454(9)
		117			0.076 76(22)			0.0768(7)

Table 1 (continued)

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
		118			0.242 23(30)			0.2422(9)
		119			0.085 85(13)			0.0859(4)
		120			0.325 93(20)			0.3258(9)
		122			0.046 29(9)			0.0463(3)
		124			0.057 89(17)			0.0579(5)
51	Sb	121		g	0.572 13(32) 2*s* C	[56]	Sb powder	0.5721(5)
		123			0.427 87(32)			0.4279(5)
52	Te	120		g	0.000 96(1) 2s_e N	[57]	–	0.0009(1)
		122			0.026 03(1)			0.0255(12)
		123			0.009 08(1)			0.0089(3)
		124			0.048 16(2)			0.0474(14)
		125			0.071 39(2)			0.0707(15)
		126			0.189 52(4)			0.1884(25)
		128			0.316 87(4)			0.3174(8)
		130			0.337 99(3)			0.3408(62)
53	I	127			1	[58]		1
54	Xe	124		g, m	0.000 952(3) 3*s* C	[59]	IRMM-2000* (Air)	0.000 95(5)
		126			0.000 890(2)			0.000 89(3)
		128			0.019 102(8)			0.019 10(13)
		129			0.264 006(82)			0.264 01(138)
		130			0.040 710(13)			0.040 71(22)
		131			0.212 324(30)			0.212 32(51)
		132			0.269 086(33)			0.269 09(55)
		134			0.104 357(21)			0.104 36(35)
		136			0.088 573(44)			0.088 57(72)
55	Cs	133			1	[23]		1
56	Ba	130			0.001 058(2) 3s_e F	[60]	–	0.0011(1)
		132			0.001 012(2)			0.0010(1)
		134			0.024 170(30)			0.0242(15)
		135			0.065 920(20)			0.0659(10)
		136			0.078 532(40)			0.0785(24)
		137			0.112 317(40)			0.1123(23)
		138			0.716 991(70)			0.7170(29)
57	La	138		g	0.000 8881(24) 2*s* N	[61]	–	0.000 8881(71)
		139			0.999 1119(24)			0.999 1119(71)
58	Ce	136		g	0.001 86(1) 2*s* C	[62]	–	0.001 86(2)
		138			0.002 51(1)			0.002 51(2)
		140			0.884 49(34)			0.884 49(51)
		142			0.111 14(34)			0.111 14(51)
59	Pr	141			1	[46]		1
60	Nd	142		g	0.271 53(19) 2*s* C	[63]	–	0.271 53(40)
		143			0.121 73(18)			0.121 73(26)
		144			0.237 98(12)			0.237 98(19)
		145			0.082 93(7)			0.082 93(12)
		146			0.171 89(17)			0.171 89(32)
		148			0.057 56(8)			0.057 56(21)
		150			0.056 38(9)			0.056 38(28)
61	Pm	–			–			–
62	Sm	144		g	0.030 78(14) 2u_c F	[64]	Kaolinite, China	0.0308(4)
		147			0.150 04(54)			0.1500(14)

Table 1 (continued)

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
		148			0.112 48(36)			0.1125(9)
		149			0.138 24(40)			0.1382(10)
		150			0.073 65(34)			0.0737(9)
		152			0.267 40(36)			0.2674(9)
		154			0.227 41(56)			0.2274(14)
63	Eu	151		g	0.478 10(42) $2s_e$ C	[65]	Monazite, China	0.4781(6)
		153			0.521 90(42)			0.5219(6)
64	Gd	152		g	0.002 029(4) $2s_e$ N	[66]	–	0.0020(3)
		154			0.021 809(4)			0.0218(2)
		155			0.147 998(17)			0.1480(9)
		156			0.204 664(6)			0.2047(3)
		157			0.156 518(9)			0.1565(4)
		158			0.248 347(16)			0.2484(8)
		160			0.218 635(7)			0.2186(3)
65	Tb	159			1	[46]		1
66	Dy	156		g	0.000 56(2) 2*s* C	[67]	Dy_2O_3, China	0.000 56(3)
		158			0.000 95(2)			0.000 95(3)
		160			0.023 29(12)			0.023 29(18)
		161			0.188 89(28)			0.188 89(42)
		162			0.254 75(24)			0.254 75(36)
		163			0.248 96(28)			0.248 96(42)
		164			0.282 60(36)			0.282 60(54)
67	Ho	165			1	[46]		1
68	Er	162		g	0.001 391(30) 2*s* C	[68]	Er_2O_3, China	0.001 39(5)
		164			0.016 006(20)			0.016 01(3)
		166			0.335 014(240)			0.335 03(36)
		167			0.228 724(60)			0.228 69(9)
		168			0.269 852(120)			0.269 78(18)
		170			0.149 013(240)			0.149 10(36)
69	Tm	169			1	[46]		1
70	Yb	168		g	0.001 23(1) 2*s* F	[69]	Yb_2O_3	0.001 23(3)
		170			0.029 82(6)			0.029 82(39)
		171			0.140 86(20)			0.140 86(140)
		172			0.216 86(19)			0.216 86(130)
		173			0.161 03(9)			0.161 03(63)
		174			0.320 25(12)			0.320 25(80)
		176			0.129 95(13)			0.129 95(83)
71	Lu	175		g	0.974 013(12) 2*s* N	[70]	–	0.974 01(13)
		176			0.025 987(12)			0.025 99(13)
72	Hf	174	[0.001 62, 0.001 62]		0.001 620(9) $2s_e$ N	[71]	–	0.0016(12)
		176	[0.052 06, 0.052 71]		0.052 604(56)			0.0526(70)
		177	[0.185 93, 0.186 06]		0.185 953(12)			0.1860(16)
		178	[0.272 78, 0.272 97]		0.272 811(22)			0.2728(28)
		179	[0.136 19, 0.136 30]		0.136 210(9)			0.1362(11)
		180	[0.350 76, 0.351 00]		0.350 802(26)			0.3508(33)
73	Ta	180			0.000 1201(8) 2*s* N	[72]	–	0.000 1201(32)
		181			0.999 8799(8)			0.999 8799(32)
74	W	180			0.001 198(2) 1*s* N	[73]	Na_2WO_4	0.0012(1)
		182			0.264 985(49)			0.2650(16)
		183			0.143 136(6)			0.1431(4)

Table 1 (continued)

Z	E	*A*	Observed interval of isotope-abundance variation in natural materials (isotope-amount fraction, *x*)	Anno-tations	Best measurement of isotopic abundances from a single terrestrial source (isotope-amount fraction, *x*)	Refs.	Material	Representative isotopic abundance (isotope-amount fraction, *x*)
1	2	3	4	5	6	7	8	9
		184			0.306 422(13)			0.3064(2)
		186			0.284 259(62)			0.2843(19)
75	Re	185			0.373 98(16) 2*s* C	[74]	NIST SRM 989*	0.3740(5)
		187			0.626 02(16)			0.6260(5)
76	Os	184		g	0.000 197(5) 1*s* N	[75]	K_2OsO_4	0.0002(2)
		186			0.015 859(44)			0.0159(64)
		187			0.019 644(12)			0.0196(17)
		188			0.132 434(19)			0.1324(27)
		189			0.161 466(16)			0.1615(23)
		190			0.262 584(14)			0.2626(20)
		192			0.407 815(22)			0.4078(32)
77	Ir	191			0.372 72(15) 1*s* N	[76]	$(NH_4)_2IrCl_6$	0.373(2)
		193			0.627 28(15)			0.627(2)
78	Pt	190			0.000 12(1) 1*s* F	[77]	IRMM-010*	0.000 12(2)
		192			0.007 82(8)			0.007 82(24)
		194			0.328 64(140)			0.328 64(410)
		195			0.337 75(79)			0.337 75(240)
		196			0.252 11(110)			0.252 11(340)
		198			0.073 57(43)			0.073 56(130)
79	Au	197			1	[15]		1
80	Hg	196			0.001 55(4) 2u_c F	[78]	NRC NIMS-1*	0.0015(1)
		198			0.100 38(10)			0.1004(3)
		199			0.169 38(9)			0.1694(12)
		200			0.231 38(6)			0.2314(9)
		201			0.131 70(12)			0.1317(9)
		202			0.297 43(9)			0.2974(13)
		204			0.068 18(6)			0.0682(4)
81	Tl	203	[0.2944, 0.2959]		0.295 24(9) 2*s* C	[79]	NIST SRM 997*	[0.2944, 0.2959]
		205	[0.7041, 0.7056]		0.704 76(9)			[0.7041, 0.7056]
82	Pb	204	[0.0104, 0.0165]	g, r	0.014 245(12) 2*s* C	[80]	NIST SRM 981*	0.014(6)
		206	[0.2084, 0.2748]		0.241 447(57)			0.241(30)
		207	[0.1762, 0.2365]		0.220 827(27)			0.221(50)
		208	[0.5128, 0.5621]		0.523 481(86)			0.524(70)
83	Bi	209			1	[15]		1
84	Po	–			–			–
85	At	–			–			–
86	Rn	–			–			–
87	Fr	–			–			–
88	Ra	–			–			–
89	Ac	–			–			–
90	Th	230	[0.000 000, 0.000 400]		0.000 011 38(2) 2u_c C	[81]	IRMM-036*	0.0002(2)
		232	[0.999 600, 1.000 000]		0.999 988 62(2)			0.9998(2)
91	Pa	231			1	[82]		1
92	U	234	[0.000 008, 0.000 059]	g, m	0.000 0542(4) 2*s* C	[83]	Namibian ore	0.000 054(5)
		235	[0.002 089, 0.007 207]		0.007 2041(36)			0.007 204(6)
		238	[0.992 739, 0.997 879]		0.992 7417(36)			0.992 742(10)

[a]Materials depleted in lithium-6 are common sources of commercial laboratory shelf reagents which is the reason for the wide interval of isotopic abundances given.

Column 9: Representative isotopic abundances. This column lists the values that, in the opinion of CIAAW, represent the isotopic abundances of chemicals and natural materials that are likely to be encountered in the laboratory. These values are consistent with the standard atomic weights to the stated precision, *i.e.* to within ±1 in the last digit quoted [3]. For 12 elements (H, Li, B, C, N, O, Mg, Si, S, Cl, Br, and Tl) having interval standard atomic-weight values the isotopic abundance of each stable isotope is given as an interval with the symbol [a, b] to denote the set of isotopic-abundance values in normal materials. The symbols a and b denote the lower and upper bounds of the interval [a, b], respectively and $a \leq$ isotopic abundance $\leq b$. For these 12 elements Column 9 entries represent the observed interval of isotope-abundance variation in natural materials; thus, entries in Columns 4 and 9 are identical. For elements with known isotope-abundance variations that do not have interval atomic-weight values, Column 9 values may differ from the values corresponding to the best measurements. The values in parentheses following the isotopic abundances indicate the range of probable isotope-abundance variations among different materials as well as measurement uncertainties. Users should be aware of the following:

a) Values in Column 9 can be used to determine the average properties of the element in materials of unspecified natural terrestrial origin, but those values may not represent the most abundant materials, and it is possible that no real sample exists having the exact values listed.
b) When precise work is to be undertaken, such as assessment of isotope-dependent properties, samples with precisely known isotopic abundances (such as those listed in Column 8 or those listed in the SNIF diagrams [3]) should be used or suitable isotopic analyses should be made.

The Commission uses nuclide masses as published in the *Atomic Mass Evaluation 2012* report by Wang *et al.* [85]. However, the uncertainty of the nuclide masses is not taken as reported. Rather, all uncertainty estimates are expanded by a factor of six in order to conform to the conservative reporting practices of CIAAW.

5 Recommended isotope ratios

In addition to the standard atomic weights and the corresponding representative isotopic composition, CIAAW has recommended standard isotope ratios for selected elements.
Nitrogen. [86] CIAAW recommends that a standard value of 272.0(3) be employed for $N(^{14}\mathrm{N})/N(^{15}\mathrm{N})$ of N_2 in air. This value is in agreement with the isotopic composition for nitrogen given in Column 6.
Argon. [87] CIAAW recommends that a standard value of 298.56(31) be employed for $N(^{40}\mathrm{Ar})/N(^{36}\mathrm{Ar})$ of argon in air. This value is in agreement with the isotopic composition for argon given in Column 6 (note that the uncertainty quoted here is not an expanded uncertainty, but rather with the coverage factor of $k = 1$).
Uranium. [3] CIAAW recommends the representative natural terrestrial isotope ratio for uranium, $N(^{238}\mathrm{U})/N(^{235}\mathrm{U}) = 137.8(1)$. This value is in agreement with the isotopic composition given in Column 9.

6 Sources of isotopic reference materials

Isotope reference materials are produced by National Metrology Institutes of many countries [84]. A selected list of isotopic-reference material vendors is listed below. More information regarding available reference materials is available from the International database for certified reference materials COMAR (www.comar.bam.de/en/)

BAM
Federal Institute for Materials Research and Testing
European Reference Materials Program
Berlin, Germany
<webshop.bam.de>

IAEA
 Isotope Hydrology Laboratory
 International Atomic Energy Agency
 Vienna, Austria
 <nucleus.iaea.org/rpst>
IRMM
 Institute for Reference Materials and Measurements
 Joint Research Centre, European Commission
 Geel, Belgium
 <irmm.jrc.ec.europa.eu>
NBL
 New Brunswick Laboratory
 U.S. Department of Energy
 Argonne, Illinois, USA
 <science.energy.gov/nbl>
NIST
 National Institute of Standards and Technology
 U.S. Department of Commerce
 Gaithersburg, Maryland, USA
 <nist.gov/srm>
NRC-CNRC
 Measurement Science and Standards
 National Research Council Canada
 Ottawa, Ontario, Canada
 <nrc.gc.ca/crm>
USGS
 Reston Stable Isotope Laboratory
 U.S. Geological Survey
 Reston, Virginia, USA
 <isotopes.usgs.gov>

7 Membership of sponsoring body

Membership of the IUPAC Inorganic Chemistry Division Committee for the period 2012–2013 was as follows:
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