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Atomic weights of the elements 2009 (IUPAC Technical Report)*,**,†

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Abstract: The biennial review of atomic-weight determinations and other cognate data has resulted in changes for the standard atomic weights of 11 elements. Many atomic weights are not constants of nature, but depend upon the physical, chemical, and nuclear history of the material. The standard atomic weights of 10 elements having two or more stable isotopes have been changed to reflect this variability of atomic-weight values in natural terrestrial materials. To emphasize the fact that these standard atomic weights are not constants of nature, each atomic-weight value is expressed as an interval. The interval is used together with the symbol [a; b] to denote the set of atomic-weight values, A_r(E), of element E in normal materials for which $a \le A_r(\mathrm{E}) \le b$. The symbols a and b denote the bounds of the interval [a; b]. The revised atomic weight of hydrogen, A_r(H), is [1.007 84; 1.008 11] from 1.007 94(7); lithium, A_r(Li), is [6.938; 6.997] from 6.941(2); boron, A_r(B), is [10.806; 10.821] from 10.811(7); carbon, A_r(C), is [12.0096; 12.0116] from 12.0107(8); nitrogen, A_r(N), is [14.006 43; 14.007 28] from 14.0067(2); oxygen, A_r(O), is [15.999 03; 15.999 77] from 15.9994(3); silicon, A_r(Si), is [28.084; 28.086] from 28.0855(3); sulfur, A_r(S), is [32.059; 32.076] from 32.065(2); chlorine, A_r(Cl), is [35.446; 35.457] from 35.453(2); and thallium, A_r(Tl), is [204.382; 204.385] from 204.3833(2). This fundamental change in the presentation of the atomic weights represents an important advance in our knowledge of the natural world and underscores the significance and contributions of chemistry to the well-being of humankind in the International Year of Chemistry 2011. The standard atomic weight of germanium, A_r(Ge), was also changed to 72.63(1) from 72.64(1).

Keywords: atomic-weight interval; atomic-weight range; conventional atomic-weight values; boron; carbon; chlorine; germanium; half-lives; hydrogen; IUPAC Inorganic Chemistry Division; lithium; nitrogen; oxygen; silicon; sulfur; thallium.

1. INTRODUCTION

Accurate atomic weights of chemical elements are fundamental in science, technology, trade, and commerce. In particular, no practical use can be made of the results of analytical chemistry without atomic weights, which relate the mass of a chemical element to its amount. Recommended atomic-weight values for use in science, industry, and trade date from F. W. Clarke's 1882 atomic-weight recalculation

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*Sponsoring body: IUPAC Inorganic Chemistry Division, Commission on Isotopic Abundances and Atomic Weights: see more details on page xxxx.

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†Dedicated to Prof. Kevin J. R. Rosman, expert scientist, former member of IUPAC's Commission on Isotopic Abundances and Atomic Weights and IUPAC's Subcommittee for Isotopic Abundance Measurement, and analytical thinker—a long-time friend of and contributor to the Commission on Isotopic Abundances and Atomic Weights

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[1] and were followed by publication in 1898 of recommended values in the annual reports of the American Chemical Society's Atomic Weights Commission [2]. From its inception in 1919, the International Union of Pure and Applied Chemistry (IUPAC) took over the careful evaluation and dissemination of atomic weights and their measurement uncertainties derived from critically assessed, published information. Recommended atomic-weight values have been published under IUPAC since 1920. In 1979 [3], the Commission on Atomic Weights and Isotopic Abundances, as it was known then, agreed that an atomic weight could be defined for any specified sample and decreed that

> "Dated Tables of Standard Atomic Weights published by the Commission refer to our best knowledge of the elements in natural [defined below] terrestrial sources."

In recent times, the Table of Standard Atomic Weights has been published biennially, and their values are virtually unchallenged throughout the world. Each standard atomic-weight value reflects the best knowledge of evaluated, published data. The most recent recommended atomic weights were published in 2009 [4]. Periodically, the history of the standard atomic-weight value of each element is reviewed, emphasizing the relevant published scientific evidence upon which decisions were based [5,6].

The Commission on Isotopic Abundances and Atomic Weights (hereafter termed the Commission) met in Vienna, Austria under the chairmanship of Prof. R. Gonfiantini from 28 to 29 July 2009, prior to the 45th IUPAC General Assembly in Glasgow, Scotland. At this meeting, the Commission reviewed recommendations of its Subcommittee on Isotopic Abundance Measurements (SIAM), which reviewed the literature from the past two years of publications, and the Commission recommended that "Isotopic compositions of the elements 2009" [7] be published. At the 2009 meeting, the Commission reviewed and accepted recommendations from the IUPAC project "Assessment of fundamental understanding of isotopic abundances and atomic weights of the chemical elements" [8] to update the Table of Standard Atomic Weights 2009 and to emphasize the fact that many atomic weights are not constants of nature as their values depend on the source of the material.

1.1 Atomic weight of an element

The atomic weight, $A_r(\mathrm{E})$, of element E in a specimen can be determined from knowledge of the atomic masses of the isotopes of that element and the corresponding mole fractions of the isotopes of that element in the specimen. The Commission used the atomic-mass evaluations of 2003 [9,10] for calculations of the atomic weights that were changed in this compilation. There are 21 elements that have only one stable isotope, defined by the Commission as having a half-life greater than 1×10^{10} a [11]. The standard atomic weight of each of these elements having a single stable isotope is derived from the atomic mass of this stable isotope [9,10]. For elements with no stable isotopes or with no radioactive isotopes having a half-life greater than 1×10^{10} a (e.g., Ra), no standard atomic weight can be calculated and no value is provided in the Table of Standard Atomic Weights. The majority of the elements have two or more stable isotopes. For these elements, the atomic weight of an element in a substance is the abundance-weighted sum of the atomic masses of its isotopes. The atomic weight in a substance P is expressed by the relation

$$A_r(\mathrm{E})_\mathrm{P} = \Sigma[x(^i\mathrm{E}) \times A_r(^i\mathrm{E})]$$

where $x(^i\mathrm{E})$ is the mole fraction of isotope $^i\mathrm{E}$ and the summation is over all stable isotopes of the element.

1.2 "Best measurement" of the isotopic abundances of an element

For several decades, the isotopic abundances of many elements with two or more stable isotopes have been measured with decreasing measurement uncertainty by means of mass spectrometry. As a result, the uncertainty in atomic-weight measurements, $U[A_r(E)]$, has improved substantially. The Commission regularly evaluates reports of isotopic abundances 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 ratio, r, or isotope-number ratio, R, of an element in a well-characterized, representative material with small 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 so 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 measurement uncertainties of random and systematic nature 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 interval 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 for Reference Materials and Measurements (IRMM), the International Atomic Energy Agency (IAEA), etc., or to isotopically unfractionated representatives of homogeneous terrestrial materials.

The Commission wishes to emphasize the need for new, calibrated isotopic-composition measurements to improve the standard atomic-weight values of a number of elements, which are still not known to a sufficiently small uncertainty, e.g., Ge, Gd, Hf, Hg, Mo, Pd, Ru, and Sm.

1.3 "Normal" material

Although uncertainties of most atomic-weight measurements have improved over the last century, by 1967 it was recognized that there were seven elements (H, B, C, O, Si, S, and Cu) whose atomic-weight uncertainties could not be reduced because of variations in the mole fractions of their isotopes in normal materials [12], and it was recognized that these isotopic-abundance variations can affect the atomic weights of some reagents [13]. By a "normal" material, the Commission means a material from a terrestrial source that satisfies the following criterion:

> "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." [5]

With improvements in analytical instrumentation during the last three decades, the number of elements with two or more isotopes that have variations in atomic-weight values in normal materials that exceed the uncertainty of the atomic weight determined from a best measurement of isotopic abundances grew to 18 elements in the 2007 Table of Standard Atomic Weights [4]. These elements having two or more stable isotopes are given footnote "r" in the Table of Standard Atomic Weights to indicate that a range in isotopic composition of normal terrestrial material prevents a more precise $A_r(E)$ from being given.

1.4 Categorization of elements by their atomic-weight and isotopic-composition variations

Because variation in isotopic composition of an element impacts its atomic weight, the Commission has undertaken assessments of variations of isotopic compositions in the published literature, both through its former Subcommittee for Natural Isotopic Fractionation and through IUPAC projects. Graphical plots of isotopic-abundance variation and atomic-weight variation were published for 15 elements: H, Li, B, C, N, O, Mg, Si, S, Cl, Ca, Cr, Fe, Cu, and Tl [14,15].

These elements can be categorized according to constraints on their standard atomic weights:

1. Elements with no stable isotopes or with no radioactive isotopes having a half-life greater than 1×10^{10} a, e.g., radon. No standard atomic weight can be calculated and no value is provided in the Table of Standard Atomic weights for these elements.
2. Elements with one stable isotope, e.g., sodium. The standard atomic weight is derived from the atomic mass of its stable isotope [9,10].
3. Elements with two or more isotopes showing no evidence of variation in atomic weight for natural terrestrial materials, or elements that currently are not being evaluated for variation in isotopic composition by an IUPAC project, e.g., tungsten.
4. Elements with two or more isotopes having variations in atomic weight in natural terrestrial materials, but these variations do not exceed the measurement uncertainty of the atomic weight derived from the “best measurement” of the isotopic abundances of an element, e.g., iron (Fig. 1).
5. Elements with two or more isotopes having variations in atomic weight in natural terrestrial materials that exceed the uncertainty of the atomic weight derived from a best measurement of isotopic abundances and have published isotopic compositions currently being evaluated in an IUPAC project, e.g., copper, which is being evaluated in the IUPAC project “Evaluation of Isotopic Abundance Variations in Selected Heavier Elements,” [16] or strontium, which is being evaluated in the IUPAC project “Evaluation of Radiogenic Abundance Variations in Selected Elements” [17].
6. Elements with two or more isotopes having variations in atomic weight in natural terrestrial materials that exceed the uncertainty of the atomic weight derived from a “best measurement” of isotopic abundances and having their upper and lower atomic-weight bounds determined by the Commission from evaluated, published data, e.g., carbon (Fig. 2).

Elements in category 3 may enter category 4 as more accurate isotopic-abundance measurements are made. Similarly, elements in category 4 can advance to category 5 as best-measurement results improve. The Commission uses the footnote “g” to identify chemical elements for which the standard atomic weight and its associated uncertainty do not include all known variations, e.g., the anomalous occurrences of isotopic composition for fissionogenic elements found at the Oklo natural nuclear reactor in Gabon. For category 3 to 6 elements, the Commission uses the footnote “m” to identify the chemical elements for which the standard atomic weight and its associated uncertainty in commercially available material do not include variations due to undisclosed or inadvertent isotopic fractionation. Periodic changes to the values and uncertainties in standard atomic weights result from improved measurements of the atomic masses, and these changes primarily impact category 2 elements.

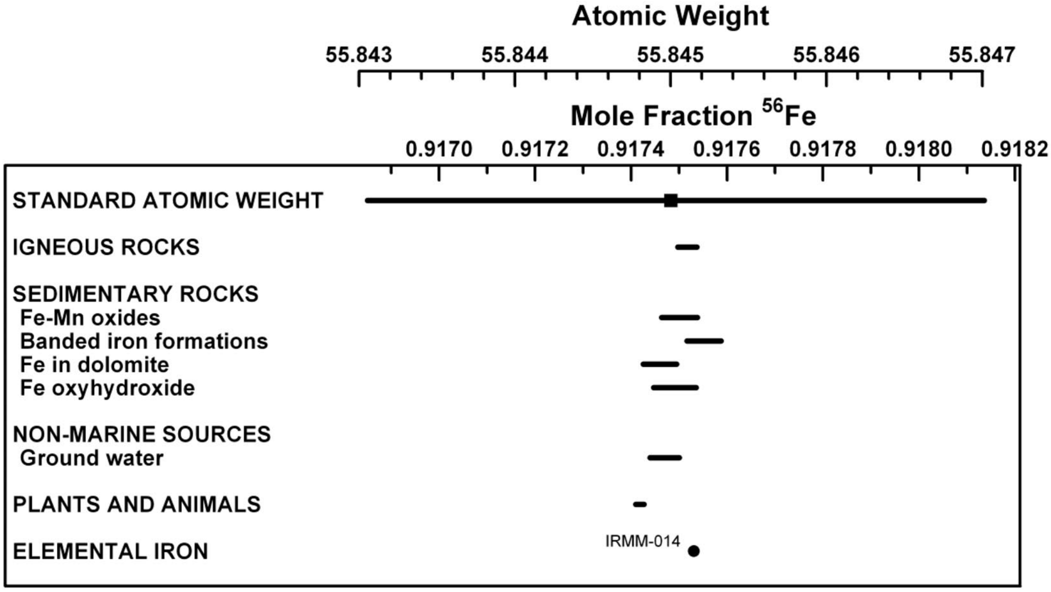

Fig. 1 Example of an element (iron) showing variation in atomic weight in natural terrestrial materials that does not exceed the uncertainty of the standard atomic weight determined from the "best measurement" of isotopic abundances (modified from [14,15]). An isotopic reference material (IRMM-014 elemental iron) is designated by a solid black circle. The current standard atomic weight of iron, 55.845(2), was established in 1993 [18]. The atomic-weight uncertainty determined from the best measurement of isotopic abundances [19] is approximately ±0.0005 and encompasses the atomic weight of all natural terrestrial materials.

1.5 Atomic-weight intervals

Atomic-weight distributions calculated from published variations in isotopic compositions can span a relatively large interval. For example, the atomic weight of carbon in normal materials spans atomic-weight values from approximately 12.0096 to 12.0116 (Fig. 2), whereas the uncertainty of the atomic weight calculated from the best measurement of the isotopic abundance of carbon is approximately 30 times smaller [7,20]; $A_r(\mathrm{C}) = 12.011\,09(3)$. The span of atomic-weight values in normal materials is termed the interval. The interval is used together with the symbol [*a*; *b*] to denote the set of values *x* for which $a \le x \le b$, where $b > a$ and where *a* and *b* are the lower and upper bounds, respectively [21]. Neither the upper nor lower bounds have any uncertainty associated with them; each is a considered decision by the Commission based on professional evaluation and judgment. Writing the standard atomic weight of carbon as "[12.0096; 12.0116]" indicates that its atomic weight in any normal material will be greater than or equal to 12.0096 and will be less than or equal to 12.0116. Thus, the atomic-weight interval is said to encompass atomic-weight values of all normal materials. The range of an interval is the difference between *b* and *a*, that is $b - a$ [21]; thus, the range of the atomic-weight interval of carbon is calculated as 12.0116 – 12.0096 = 0.0020. The standard atomic weight of an element should not be expressed as the average of *a* and *b* with an associated uncertainty of ± half of the range.

The lower bound of an atomic-weight interval is determined from the lowest atomic weight determined by the Commission's evaluations and taking into account the uncertainty of the measurement. Commonly, an isotope-delta measurement is the basis for the determination of the bound [14,15]. In addition to the uncertainty in the delta measurement, the uncertainty in the atomic weight of the material anchoring the delta scale also must be taken into account. The latter is the uncertainty in relating a delta scale to an atomic-weight scale [14,15]. If substance P is the normal terrestrial material having the lowest atomic weight of element E, then

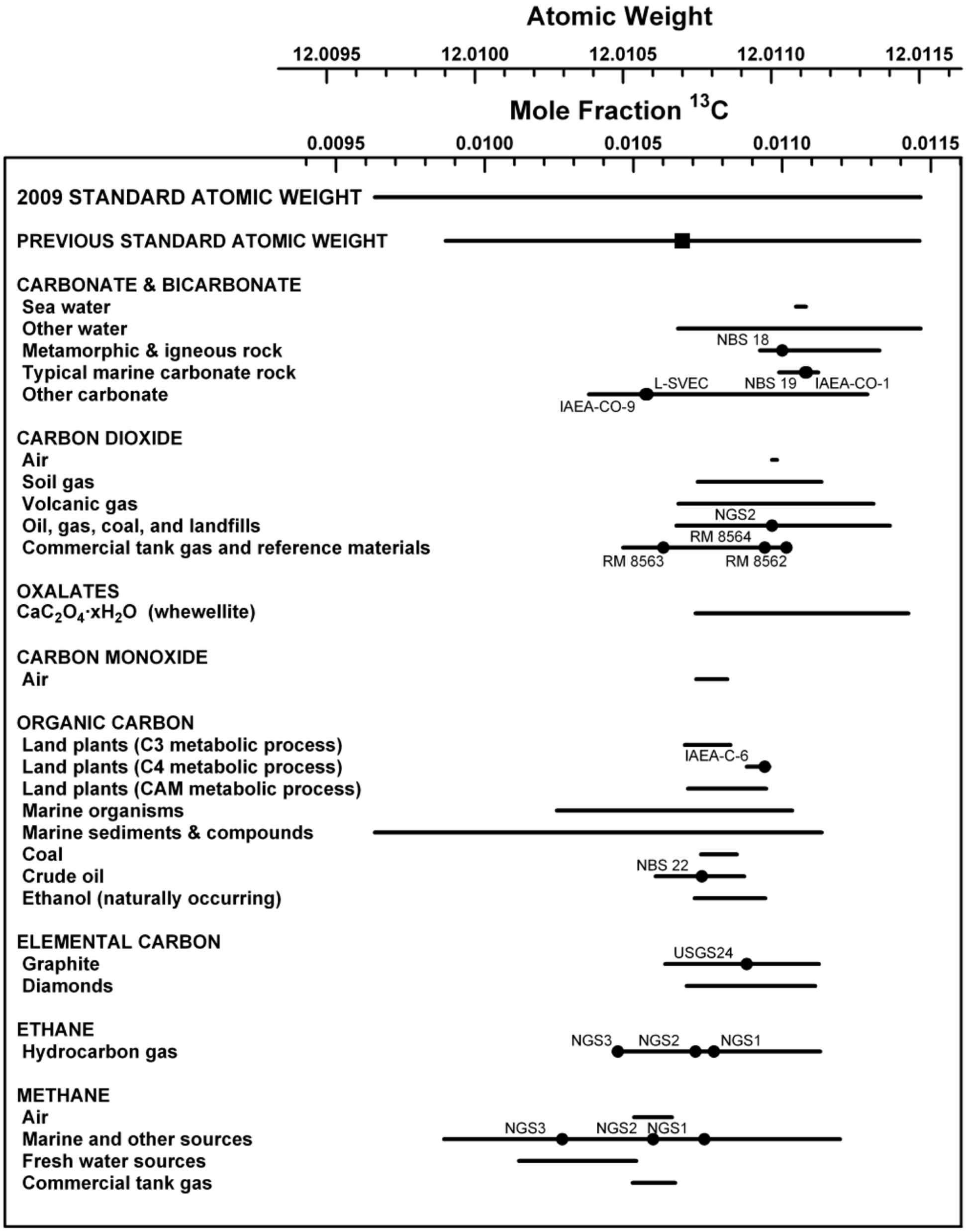

Fig. 2 Variation in atomic weight with isotopic composition of selected carbon-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of carbon [4] was 12.0107(8). The atomic-weight uncertainty of the "best measurement" of isotopic abundance [7,20] is approximately ±0.000 027, which is about 30 times smaller than the uncertainty of the 2007 standard atomic weight [4].

$$\text{lower bound} = \text{lowest } A_\text{r}(\text{E})_\text{P} - U[A_\text{r}(\text{E})]_\text{P}$$

where $U[A_\text{r}(\text{E})]_\text{P}$ is the combined uncertainty that incorporates the uncertainty in the measurement of the delta value of substance P and the uncertainty in relating the delta-value scale to the atomic-weight scale. For example, consider the lower bound for carbon. The substance with the lowest measured ^{13}C abundance is crocetane (2,6,11,15-tetramethylhexadecane) produced at cold seeps of the eastern Aleutian subduction zone [22]. For this specimen, $A_r(C) = 12.009\,662$, where the atomic weight is determined from an isotope-delta value [14,15]. The uncertainty of the delta measurement is equivalent to an uncertainty in the atomic weight of 0.000 003. The uncertainty in relating the carbon-delta scale to its atomic-weight scale corresponds to an atomic-weight uncertainty of 0.000 027. Therefore, the combined uncertainty in the lowest atomic-weight value of carbon is $U[A_r(E)]_P = (0.000\,003^2 + 0.000\,027^2)^{1/2} = 0.000\,027$ and the lower bound = 12.009 662 – 0.000 027 = 12.009 635.

The upper bound is calculated in an equivalent manner except that the combined uncertainty is added to the atomic-weight value of the substance P with the highest measured atomic weight.

upper bound = highest $A_r(E)_P + U[A_r(E)]_P$

For the example of carbon, the substance with the highest ^{13}C-abundance fraction is deep-sea pore water, and it has an atomic-weight value of 12.011 505. The uncertainty in the atomic-weight value of this substance, due to the uncertainty in the delta-value determination, is 0.000 003. As with the lower bound, the uncertainty in relating the carbon-delta scale to its atomic-weight scale results in an atomic-weight uncertainty of 0.000 027. Thus, the upper bound = $12.011\,505 + (0.000\,003^2 + 0.000\,027^2)^{1/2} = 12.011\,532$.

The uncertainties of the delta measurements and the uncertainty of the atomic weight derived from the best measurement of isotopic abundances constrain the number of significant figures in the atomic-weight values of the upper and lower bounds. For carbon, the fifth digit after the decimal point is uncertain because of the uncertainty value of 0.000 027. Therefore, the number of significant digits in the atomic-weight value is reduced to four figures after the decimal point. The Commission may recommend additional conservatism and reduce the number of significant figures further. For the lower bound of carbon, 12.009 635 is truncated to 12.0096. For an upper bound, the trailing digit is increased to ensure the atomic-weight interval encompasses the atomic-weight values of all normal materials. In the case of carbon, the upper bound is adjusted from 12.011 532 to 12.0116 to express four digits after the decimal point. The lower and upper bounds are evaluated so that the number of significant digits in each is identical. If a value ends with a zero, it may need to be included in the value to express the required number of digits. The following are examples of lower and upper atomic-weight bounds for oxygen that could be published by the Commission in its various tables.

15.99903	15.99977	Unabridged Table of Standard Atomic Weights
15.9990	15.9998	Abridged to six figures
15.999	16.000	Table of Standard Atomic Weights Abridged to Five Figures
15.99	16.00	Table of Standard Atomic Weights Abridged to Four Figures

Rules and comments on determining values of atomic-weight intervals of elements having two or more stable isotopes include:

1. The variation in atomic-weight values of an element is termed an atomic-weight “interval” with the symbol [*a*; *b*], where *a* and *b* are the lower and upper bounds, respectively, of the interval; thus, for element E, $a \le A_r(E) \le b$.
2. The standard atomic weight of an element expressed as an interval, [*a*; *b*], should not be expressed as the average of *a* and *b* with an associated uncertainty equal to half of the difference between *b* and *a*.
3. The atomic-weight interval encompasses atomic-weight values of all normal materials.
4. The atomic-weight interval is the standard atomic weight and is the best knowledge of atomic weights of natural terrestrial sources.
5. The atomic-weight interval and range should not be confused. The atomic-weight range is equal to $b - a$, where *a* and *b* are the lower and upper bounds, respectively.

6. The lower and upper bounds commonly are determined from the lowest and highest isotope-delta values of normal materials, taking into account uncertainties of the isotope-delta measurements and uncertainty in relating the isotope-delta scale to the atomic-weight scale of an element.
7. Both lower and upper bounds are consensus values, and neither has any uncertainty associated with it.
8. The number of significant figures in the lower and upper bounds are adjusted so that mass-spectrometric measurement uncertainties do not impact the bounds.
9. The number of significant figures in the lower and upper bounds should be identical. A zero as a trailing digit in a value may be needed and is acceptable.
10. The atomic-weight interval is selected conservatively so that changes in the Table of Standard Atomic Weights are needed infrequently.
11. The atomic-weight interval is given as precisely as possible and should have as many digits as possible consistent with the previously stated rules.
12. Values of atomic-weight intervals are updated in the Table of Standard Atomic Weights by IUPAC's Commission on Isotopic Abundances and Atomic Weights following completion of an IUPAC project reviewing the published literature for peer-reviewed, isotopic-abundance data.
13. If the variation in isotopic composition in normal materials of an element is under evaluation by an IUPAC project, a footnote "r" may be retained in the Table of Standard Atomic Weights until the project completes its evaluation in order that changes to Tables are infrequent. Currently, such elements include He, Ni, Cu, Zn, Se, Sr, Ar, and Pb.

2. TABLES OF STANDARD ATOMIC WEIGHTS IN ALPHABETIC AND ATOMIC-NUMBER ORDER

The Table of Standard Atomic Weights 2009 is given in alphabetical order of the 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. With minor exceptions covered by footnotes, the Table of Standard Atomic Weights is intended to apply to all samples from natural terrestrial occurrences, as well as to materials in commerce, samples found in laboratories involved in chemical investigations, and samples in technological applications. The Table of Standard Atomic Weights does not apply to extraterrestrial materials or to materials with deliberately altered isotopic compositions.

To indicate that standard atomic weights of elements with two or more stable isotopes are not constants of nature, the Table of Standard Atomic Weights 2009 lists atomic-weight intervals for the standard atomic weights of 10 such elements (B, C, Cl, H, Li, N, O, S, Si, and Tl). These elements had footnote "r" in the Table of Standard Atomic Weights 2007 [4], and this footnote is not retained for these elements. For all of these elements, a graphical plot of substance, isotopic abundance, and atomic weight is provided in this report, and figure numbers are provided in Tables 1 and 2 for the interested reader.

For elements within categories 2 to 5 (see Section 1.4 for category descriptions), a decisional uncertainty, $U[A_r(\mathrm{E})]$, is given in parentheses following the last significant figure to which it is attributed. If there is no specific statement on the distribution of possible values, then the distribution should be regarded as a rectangular distribution. The interval $A_r(\mathrm{E})–U[A_r(\mathrm{E})]$ to $A_r(\mathrm{E})+U[A_r(\mathrm{E})]$ may be expected to encompass almost all samples from natural terrestrial occurrences as well as materials in commerce and samples found in technological applications or in laboratories involved in scientific investigations.

For all elements for which a change in the standard atomic weight is recommended, the Commission by custom makes a statement on the reason for the change and includes a list of recommended values over a period in excess of the last 100 years, which are taken from [23] and subsequent Commission publications. Values before the formation of the International Committee on Atomic Weights in 1900 come from [24].

The names and symbols for those elements with atomic numbers 113 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* [25]. Each systematic name and symbol 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 occurring before “nil”, and the “i” of “bi” and of “tri” is deleted when occurring before “ium”.

Table 1 Standard atomic weights 2009.
[Using $A_\mathrm{r}(^{12}\mathrm{C}) = 12$ as reference, where $^{12}\mathrm{C}$ is an unbound neutral atom in its nuclear and electronic ground state.]

The atomic weights, $A_\mathrm{r}(\mathrm{E})$, of many elements vary due to variations in the abundances of their isotopes in natural terrestrial materials. For 10 of these elements, an atomic-weight interval is given with the symbol [*a*; *b*] to denote the set of atomic-weight values in normal materials; thus, $a \le A_\mathrm{r}(\mathrm{E}) \le b$ for element E. The symbols *a* and *b* denote the bounds of the interval [*a*; *b*]. Figures in this report display distributions of atomic-weight variation for specified elements. If a more accurate $A_\mathrm{r}(\mathrm{E})$ value is required, it must be determined for the specific material. For 74 elements, $A_\mathrm{r}(\mathrm{E})$ values and their decisional uncertainties (in parentheses, following the last significant figure to which they are attributed) are given. 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 $A_\mathrm{r}(\mathrm{E})$ or may lie outside the values listed. Names of elements with atomic number 113 to 118 are provisional; they have been reported in the peer-reviewed, scientific literature, but they have not yet been named by IUPAC.

Alphabetic order in English

Element name	Symbol	Atomic number	Atomic weight	See also Table/Figure	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	[10.806; 10.821]	6/5	m
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	[12.0096; 12.0116]	6/2	
cerium	Ce	58	140.116(1)		g

(*continues on next page*)

Table 1 (*Continued*).

Alphabetic order in English					
Element name	Symbol	Atomic number	Atomic weight	See also Table/Figure	Footnotes
chlorine	Cl	17	[35.446; 35.457]	6/10	m
chromium	Cr	24	51.9961(6)		
cobalt	Co	27	58.933 195(5)		
copernicium*	Cn	112			
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	72.63(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 84; 1.008 11]	6/3	m
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	[6.938; 6.997]	6/4	m
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
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	[14.006 43; 14.007 28]	6/6	
nobelium*	No	102			

(*continues on next page*)

Table 1 (*Continued*).

Alphabetic order in English					
Element name	Symbol	Atomic number	Atomic weight	See also Table/Figure	Footnotes
osmium	Os	76	190.23(3)		g
oxygen	O	8	[15.999 03; 15.999 77]	6/7	
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	[28.084; 28.086]	6/8	
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	[32.059; 32.076]	6/9	
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	[204.382; 204.385]	6/11	
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)		
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

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Table 1 (*Continued*).

Element name	Symbol	Atomic number	Atomic weight	See also Table/Figure	Footnotes
yttrium	Y	39	88.905 85(2)		
zinc	Zn	30	65.38(2)		r
zirconium	Zr	40	91.224(2)		g

Alphabetic order in English

*Element has no stable isotopes. 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.

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 the material 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 2009.
[Using $A_r(^{12}C) = 12$ as reference, where ^{12}C is an unbound neutral atom in its nuclear and electronic ground state.]

The atomic weights, A_r(E), of many elements vary due to variations in the abundances of their isotopes in natural terrestrial materials. For 10 of these elements, an atomic-weight interval is given with the symbol [*a*; *b*] to denote the set of atomic-weight values in normal materials; thus, $a \le A_r(E) \le b$ for element E. The symbols *a* and *b* denote the bounds of the interval [*a*; *b*]. Figures in this report display distributions of atomic-weight variation for specified elements. If a more accurate A_r(E) value is required, it must be determined for the specific material. For 74 elements, A_r(E) values and their decisional uncertainties (in parentheses, following the last significant figure to which they are attributed) are given. 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) or may lie outside the values listed. Names of elements with atomic number 113 to 118 are provisional; they have been reported in the peer-reviewed, scientific literature, but they have not yet been named by IUPAC.

Order of atomic number

Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
1	hydrogen	H	[1.007 84; 1.008 11]	6/3	m
2	helium	He	4.002 602(2)		g r
3	lithium	Li	[6.938; 6.997]	6/4	m
4	beryllium	Be	9.012 182(3)		
5	boron	B	[10.806; 10.821]	6/5	m
6	carbon	C	[12.0096; 12.0116]	6/2	
7	nitrogen	N	[14.006 43; 14.007 28]	6/6	
8	oxygen	O	[15.999 03; 15.999 77]	6/7	
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	[28.084; 28.086]	6/8	
15	phosphorus	P	30.973 762(2)		

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Table 2 (*Continued*).

Order of atomic number					
Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
16	sulfur	S	[32.059; 32.076]	6/9	
17	chlorine	Cl	[35.446; 35.457]	6/10	m
18	argon	Ar	39.948(1)		g r
19	potassium	K	39.0983(1)		
20	calcium	Ca	40.078(4)		
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	72.63(1)		
33	arsenic	As	74.921 60(2)		
34	selenium	Se	78.96(3)		
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
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

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Table 2 (*Continued*).

Order of atomic number					
Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
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	173.054(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	[204.382; 204.385]	6/11	
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			
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			

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number					
Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
110	darmstadtium*	Ds			
111	roentgenium*	Rg			
112	copernicium *	Cn			
113	ununtrium*	Uut			
114	ununquadium*	Uuq			
115	ununpentium*	Uup			
116	ununhexium*	Uuh			
118	ununoctium*	Uuo			

*Element has no stable isotopes. 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.

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 the material 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.

3. COMMENTS ON ATOMIC WEIGHTS AND ANNOTATIONS OF SELECTED ELEMENTS

Brief descriptions are given for the changes to the Table of Standard Atomic Weights resulting from the Commission's meeting in 2009. All but one of the changes are due to addition of atomic-weight intervals to the Table to point out that standard atomic weights of many elements are variable, not constants of nature. The upper and lower bounds of these intervals are determined during comprehensive IUPAC-supported evaluations of published, peer-reviewed literature. It is not the intent of the Commission to carry out comprehensive reviews of the literature biennially and provide biennial updates of these atomic-weight intervals.

3.1 Hydrogen

The Commission has changed the recommended value for the standard atomic weight of hydrogen, A_r(H), to the atomic-weight interval [1.007 84; 1.008 11] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of hydrogen [14,15]. This change in the standard atomic weight of hydrogen is intended to emphasize the fact that the atomic weight of hydrogen is not a constant of nature but depends upon the source of the material (Fig. 3). The lower bound of the atomic-weight interval corresponds to hydrogen in natural gas [26], and the upper bound corresponds to benzaldehyde reagent produced by toluene catalytic oxidation [27]. The previous value of standard atomic weight, A_r(H) = 1.007 94(7), recommended in 1981, was a Commission decision to expand the uncertainty to cover better the range of all terrestrial aqueous and gaseous sources of hydrogen [28]. One of the problems with the value of A_r(H) = 1.007 94(7) is that finding a specimen with an atomic weight of 1.007 94 would be challenging (see Fig. 3). For example, the atomic weight of hydrogen in most water in the hydrologic system is greater than 1.007 97. In the Table of Standard Atomic Weights 2007 [4], hydrogen was assigned the footnotes "g", "m", and "r". Only footnote "m" is retained; this will alert the reader that commercial materials can be found that have

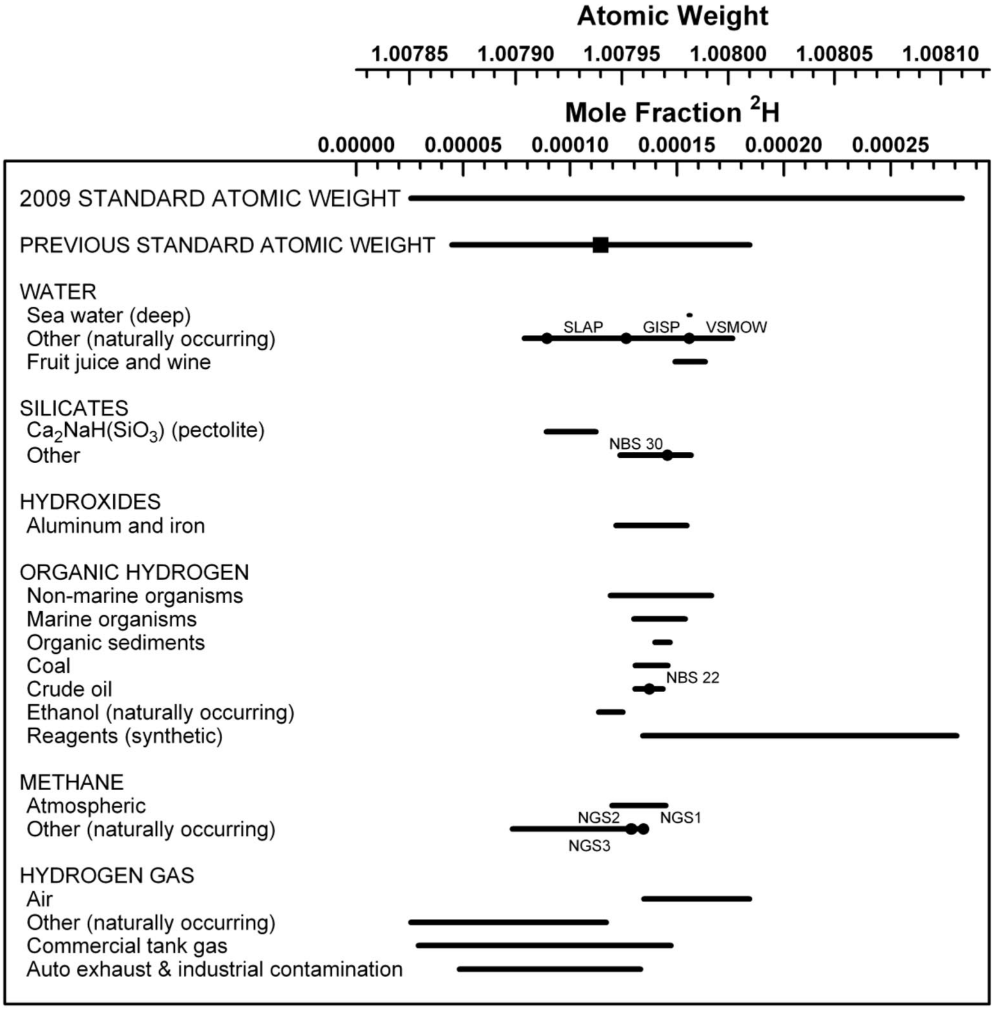

Fig. 3 Variation in atomic weight with isotopic composition of selected hydrogen-bearing materials (modified from [14,15], taking into account [27]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of hydrogen was 1.00794(7). The atomic-weight uncertainty of the "best measurement" of isotopic abundance [7,29] is approximately ±0.00000005, which is about 1000 times smaller than the uncertainty of the 2007 standard atomic weight [4].

undergone undisclosed or inadvertent isotopic fractionation. Historical values of A_r(H) include [23]: 1882, 1.00; 1894, 1.008; 1931, 1.0078; 1938, 1.0081; 1940, 1.0080; 1961, 1.00797; 1969, 1.0080(3); 1971, 1.0079(1).

3.2 Lithium

The Commission has changed the recommended value for the standard atomic weight of lithium, A_r(Li), to the atomic-weight interval [6.938; 6.997] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of lithium [14,15]. This change in the standard atomic weight of lithium is intended to emphasize the fact that the atomic weight of lithium is not a constant of nature but depends upon the source of the material (Fig. 4).

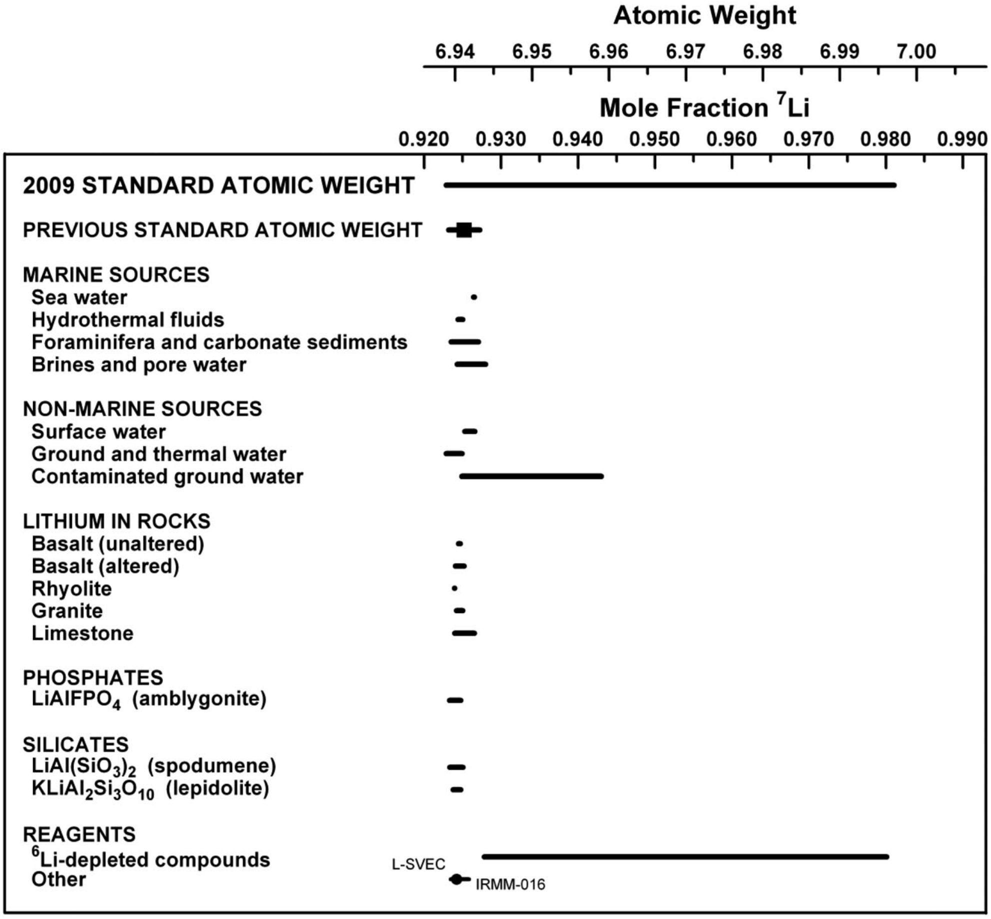

Fig. 4 Variation in atomic weight with isotopic composition of selected lithium-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of lithium was 6.941(2). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,30] is approximately ±0.000 24, which is about eight times smaller than the uncertainty of the 2007 standard atomic weight [4].

The lower bound of the atomic-weight interval corresponds to lithium dissolved in groundwater [15], and the upper bound corresponds to lithium in laboratory reagents, fractionated by removal of ^{6}Li for use in hydrogen bombs [31]. The previous standard atomic-weight value A_r(Li) = 6.941(2), recommended in 1983 [32], was based on mass-spectrometric measurements [33] and a consideration of variability in isotopic abundance of samples from several sources. In the Table of Standard Atomic Weights 2007 [4], lithium was assigned the footnotes “g”, “m”, and “r”. Only the footnote “m” is retained; this will alert readers that isotopically fractionated commercial materials might exist with atomic weights outside the interval given, although the Commission is not aware of such materials. Historical values of A_r(Li) include [23]: 1882, 7.02; 1896, 7.03; 1909, 7.00; 1911, 6.94; 1925, 6.940; 1961, 6.939(3); 1969, 6.941(3).

3.3 Boron

The Commission has changed the recommended value for the standard atomic weight of boron, A_r(B), to the atomic-weight interval [10.806; 10.821] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of boron [14,15]. This change in the standard atomic weight of boron is intended to emphasize the fact that the atomic weight of boron is not a constant of nature but depends upon the source of the material (Fig. 5). The lower bound of the atomic-weight interval corresponds to boron in the mineral kornerupine from Antarctica [34], and the upper bound corresponds to boron in a volcanic crater lake [35]. The previous standard atomic-weight value A_r(B) = 10.811(7), recommended in 1995 [36], was a Commission decision to expand the uncertainty so that boron in sea water would be included in the standard atomic weight. In the Table of Standard Atomic Weights 2007 [4], boron was assigned the footnotes "g", "m", and "r". Only the footnote "m" is retained; this will alert readers that isotopically fractionated commercial materials might exist with atomic weights outside the interval given. However, the Commission is not aware of such materials. Historical values of A_r(B) include [23]: 1882, 10.97; 1894, 11; 1896, 10.95; 1900, 11.0; 1919, 10.9; 1925, 10.82; 1961, 10.811(3); 1969, 10.81(1); 1983, 10.811(5).

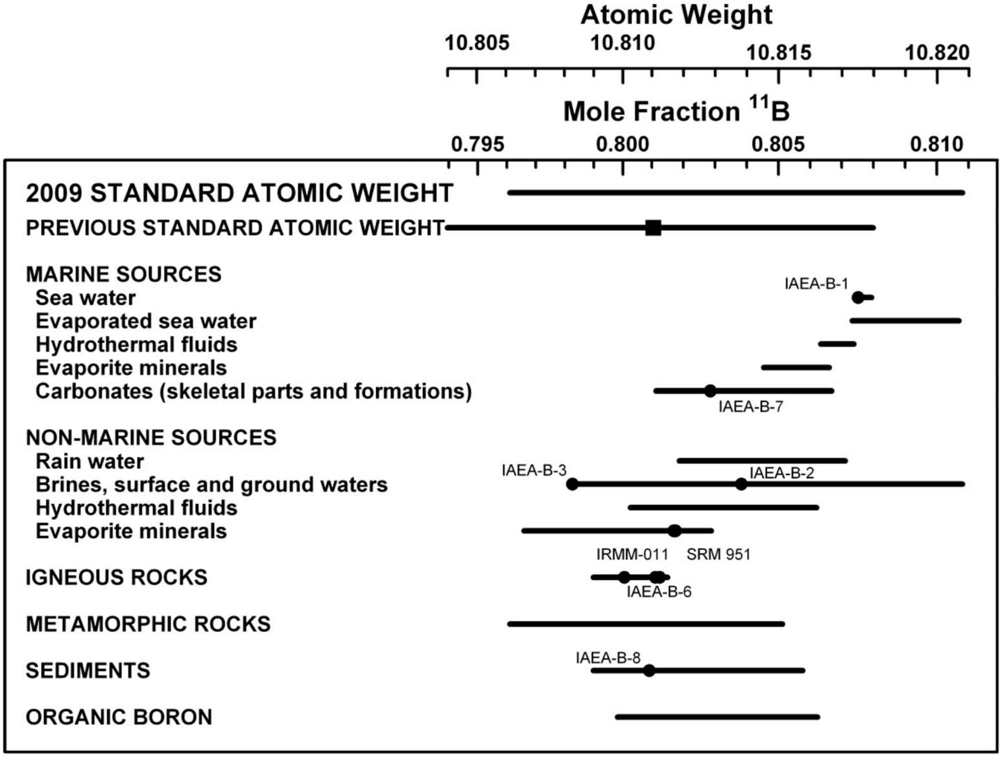

Fig. 5 Variation in atomic weight with isotopic composition of selected boron-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of boron was 10.811(7). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,37] is approximately ±0.0002, which is 35 times smaller than the uncertainty of the 2007 standard atomic weight [4].

3.4 Carbon

The Commission has changed the recommended value for the standard atomic weight of carbon, A_r(C), to the atomic-weight interval [12.0096; 12.0116] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of carbon [14,15]. This change in the standard atomic weight of carbon is intended to emphasize the fact that the atomic weight of carbon is not a constant of nature but depends upon the source of the material (Fig. 2). The lower bound of the atomic-weight interval corresponds to carbon in crocetane (2,6,11,15-tetramethylhexadecane) produced at cold seeps of the eastern Aleutian subduction zone [38], and the upper bound corresponds to carbon from deep-sea pore waters [39]. The previous standard atomic-weight value A_r(C) = 12.0107(8), recommended in 1995 [36], was a Commission decision to decrease the uncertainty of A_r(C). In the Table of Standard Atomic Weights 2007 [4], carbon was assigned the footnotes "g" and "r". Neither is retained in the 2009 Table of Standard Atomic Weights. Historical values of A_r(C) include [23]: 1882, 12.00; 1894, 12; 1896, 12.01; 1898, 12.00; 1916, 12.005; 1925, 12.000; 1931, 12.00; 1937, 12.01; 1938, 12.010; 1953, 12.007; 1961, 12.01115(5); 1969, 12.011(1).

3.5 Nitrogen

The Commission has changed the recommended value for the standard atomic weight of nitrogen, A_r(N), to the atomic-weight interval [14.00643; 14.00728] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of nitrogen [14,15]. This change in the standard atomic weight of nitrogen is intended to emphasize the fact that the atomic weight of nitrogen is not a constant of nature but depends upon the source of the material (Fig. 6). The lower bound of the atomic-weight interval corresponds to nitrogen in reagent KNO_2 [15], and the upper bound corresponds to nitrogen in nitrate in Antarctic ice [40]. The previous standard atomic-weight value A_r(N) = 14.0067(2), recommended in 1999 [41], was a Commission decision to expand the uncertainty so that nitrogen in most natural terrestrial occurrences would be included in its standard atomic weight. In the Table of Standard Atomic Weights 2007 [4], nitrogen was assigned the footnotes "g" and "r". Neither is retained in the 2009 Table of Standard Atomic Weights. Historical values of A_r(N) include [23]: 1882, 14.03; 1895, 14.05; 1896, 14.04; 1907, 14.01; 1919, 14.008; 1961, 14.0067(3); 1969, 14.0067(1); 1985, 14.00674(7).

3.6 Oxygen

The Commission has changed the recommended value for the standard atomic weight of oxygen, A_r(O), to the atomic-weight interval [15.99903; 15.99977] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of oxygen [14,15]. This change in the standard atomic weight of oxygen is intended to emphasize the fact that the atomic weight of oxygen is not a constant of nature but depends upon the source of the material (Fig. 7). The lower bound of the atomic-weight interval corresponds to oxygen in Antarctic precipitation [45], and the upper bound corresponds to oxygen in marine N_2O [46]. The previous standard atomic-weight value A_r(O) = 15.9994(3), recommended in 1969 [47], was a Commission decision to expand the uncertainty so that oxygen in most natural terrestrial occurrences would be included in its standard atomic weight. In the Table of Standard Atomic Weights 2007 [4], oxygen was assigned the footnotes "g" and "r". Neither is retained in the 2009 Table of Standard Atomic Weights. Historical values of A_r(O) include [23]: 1882, 16.00; 1894, 16.000; 1931, 16.0000; 1951, 16; 1961, 15.9994.

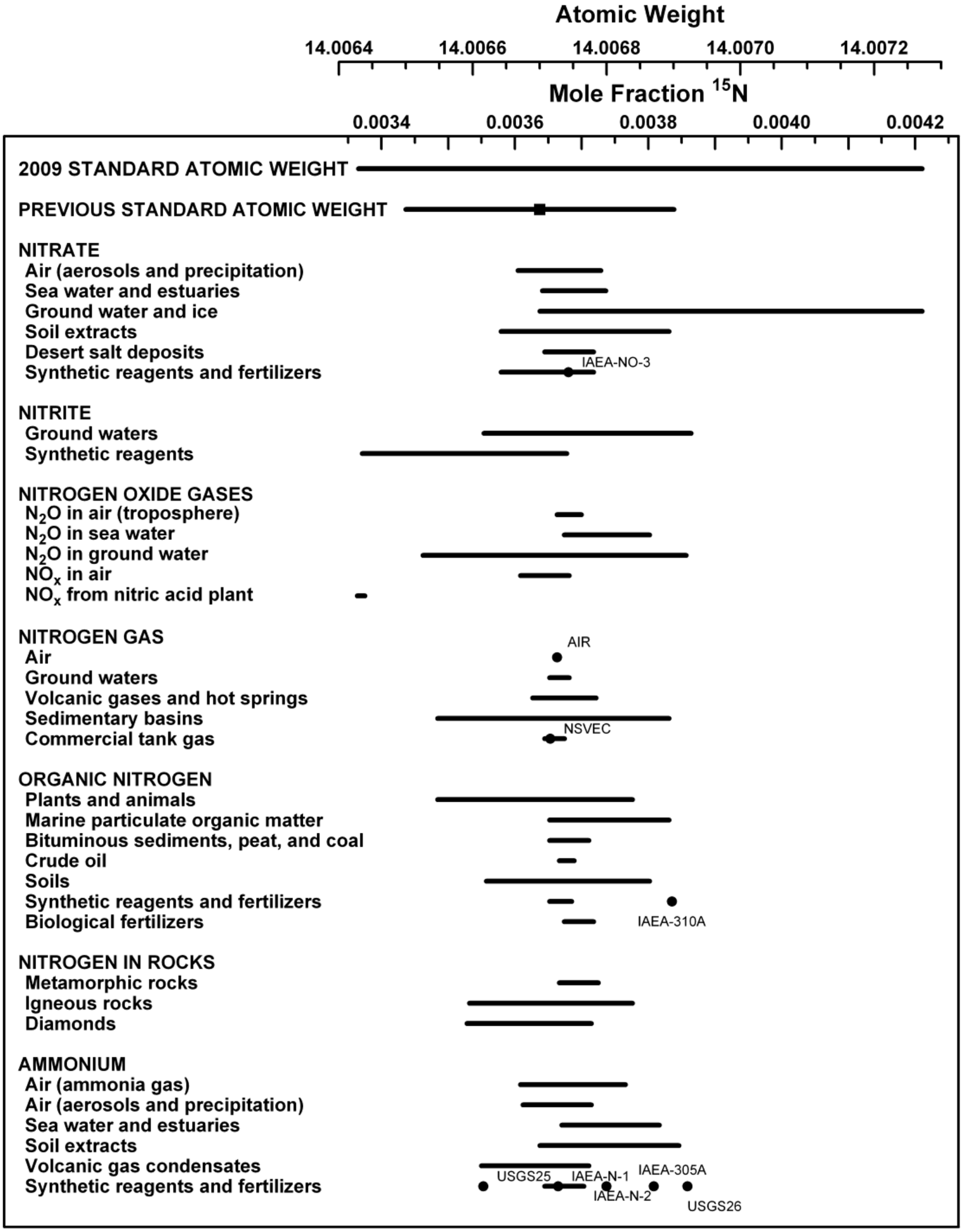

Fig. 6 Variation in atomic weight with isotopic composition of selected nitrogen-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of nitrogen was 14.0067(2). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,42] is approximately ±0.000 004, which is about fifty times smaller than the uncertainty of the 2007 standard atomic weight [4].

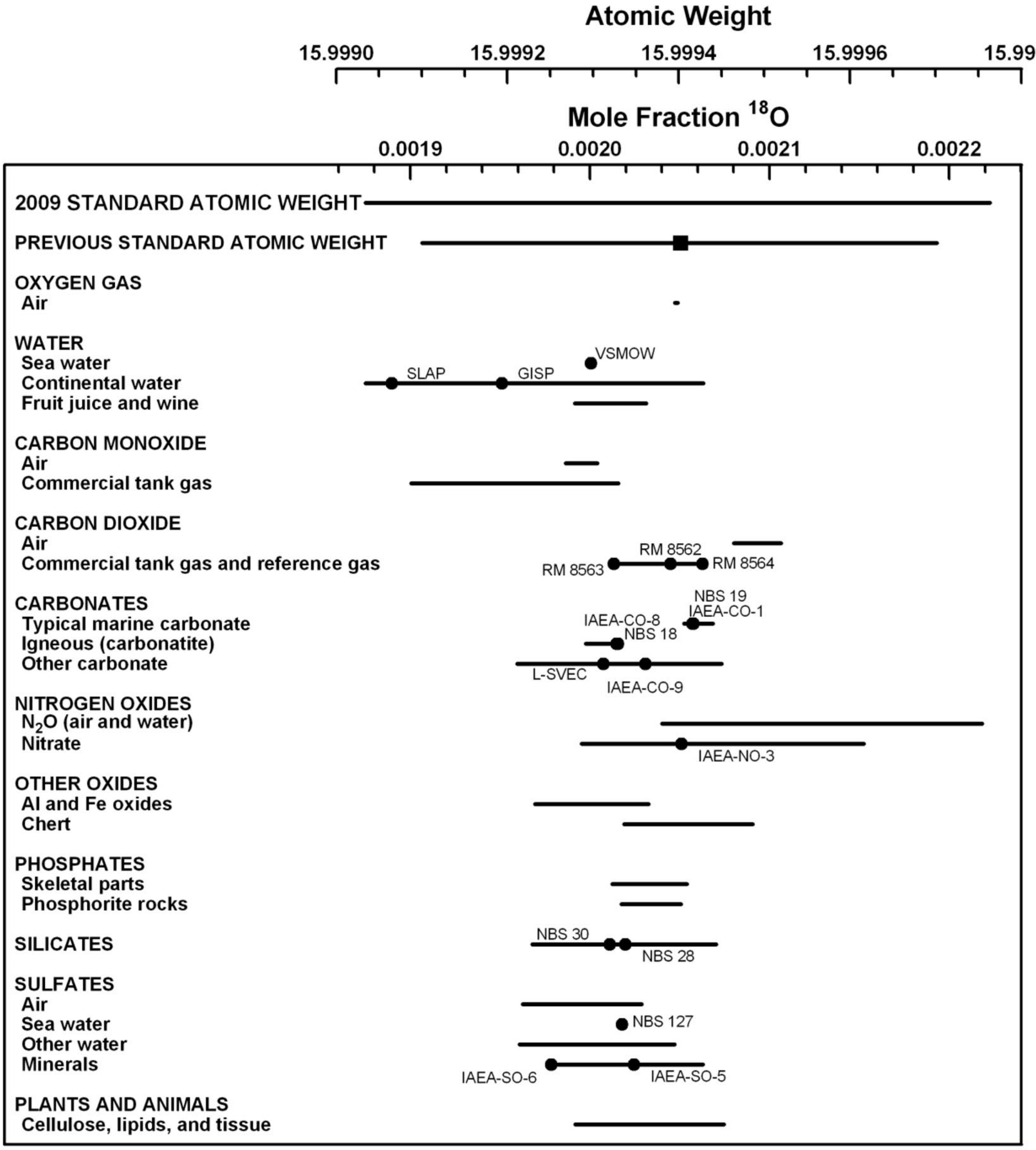

Fig. 7 Variation in atomic weight with isotopic composition of selected oxygen-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of oxygen was 15.9994(3). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,43,44] is approximately ±0.000 001, which is about 300 times smaller than the uncertainty of the 2007 standard atomic weight [4].

3.7 Silicon

The Commission has changed the recommended value for the standard atomic weight of silicon, A_r(Si), to the atomic-weight interval [28.084; 28.086] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of silicon [14,15] taking into account [48,49]. This change in the standard atomic weight of silicon is intended to emphasize the fact that the atomic weight of silicon is not a constant of nature but depends upon the source of the material (Fig. 8). The lower bound of the atomic-weight interval corresponds to silicon from precipitated siliceous cement in sandstone [48], and the upper bound corresponds to silicon in rice grains [49]. The previous standard atomic-weight value A_r(Si) = 28.0855(3), recommended in 1975 [51], was based on superior mass-spectrometric measurements [52]. In the Table of Standard Atomic Weights 2007 [4], silicon was assigned the footnote “r”, which is not retained in the 2009 Table of Standard Atomic Weights. Historical values of A_r(Si) include [23]: 1882, 28.26; 1894, 28.4; 1909, 28.3; 1922, 28.1; 1925, 28.06; 1951, 28.09; 1961, 28.086; 1969, 28.086(3).

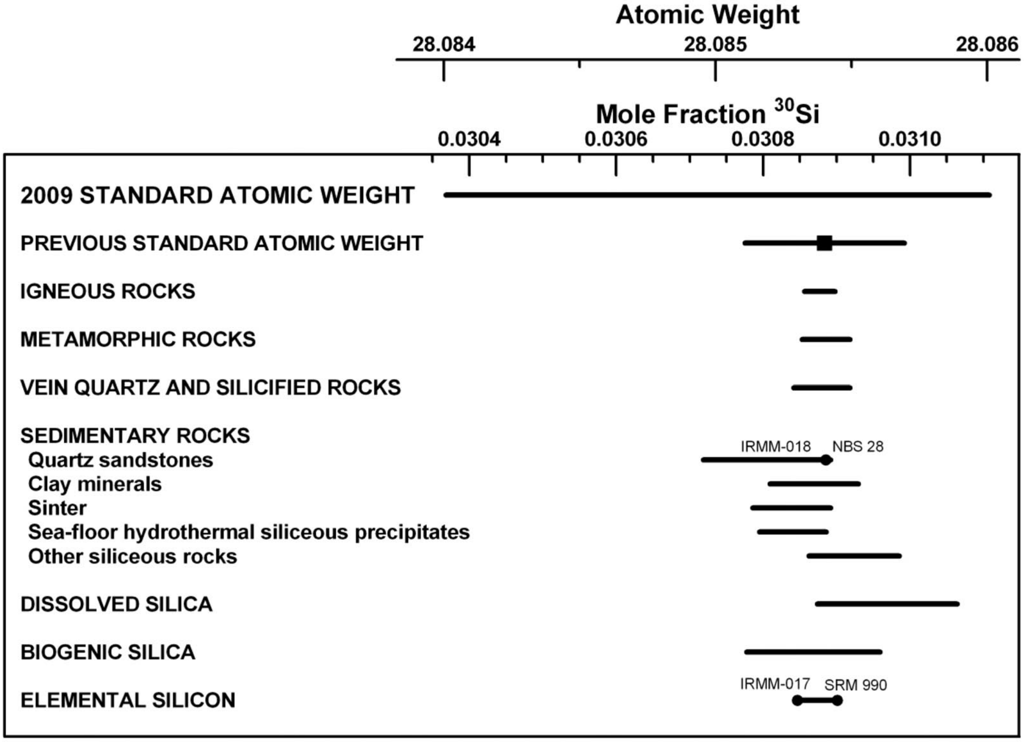

Fig. 8 Variation in atomic weight with isotopic composition of selected silicon-bearing materials (modified from [14,15]) taking into account [48,49]. Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of silicon was 28.0855(3). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,50] is approximately ±0.000 007, which is about 40 times smaller than the uncertainty of the 2007 standard atomic weight [4].

3.8 Sulfur

The Commission has changed the recommended value for the standard atomic weight of sulfur, A_r(S), to the atomic-weight interval [32.059; 32.076] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of sulfur [14,15]. This change in the standard atomic weight of sulfur is intended to emphasize the fact that the atomic weight of sulfur is not a constant of nature but depends upon the source of the material (Fig. 9). The lower bound of the atomic-weight interval corresponds to sulfur from HS^- under ice cover in a sewage treatment lagoon [15], and the upper bound corresponds to sulfur in dissolved sulfate in pore fluids in deep ocean sediments undergoing bacterial reduction [53]. The previous standard atomic-weight value A_r(S) = 32.065(5), recommended in 1999 [41], was based on the Commission decision to move the value of the standard atomic weight nearer to that of Cañon Diablo troilite and, in the process,

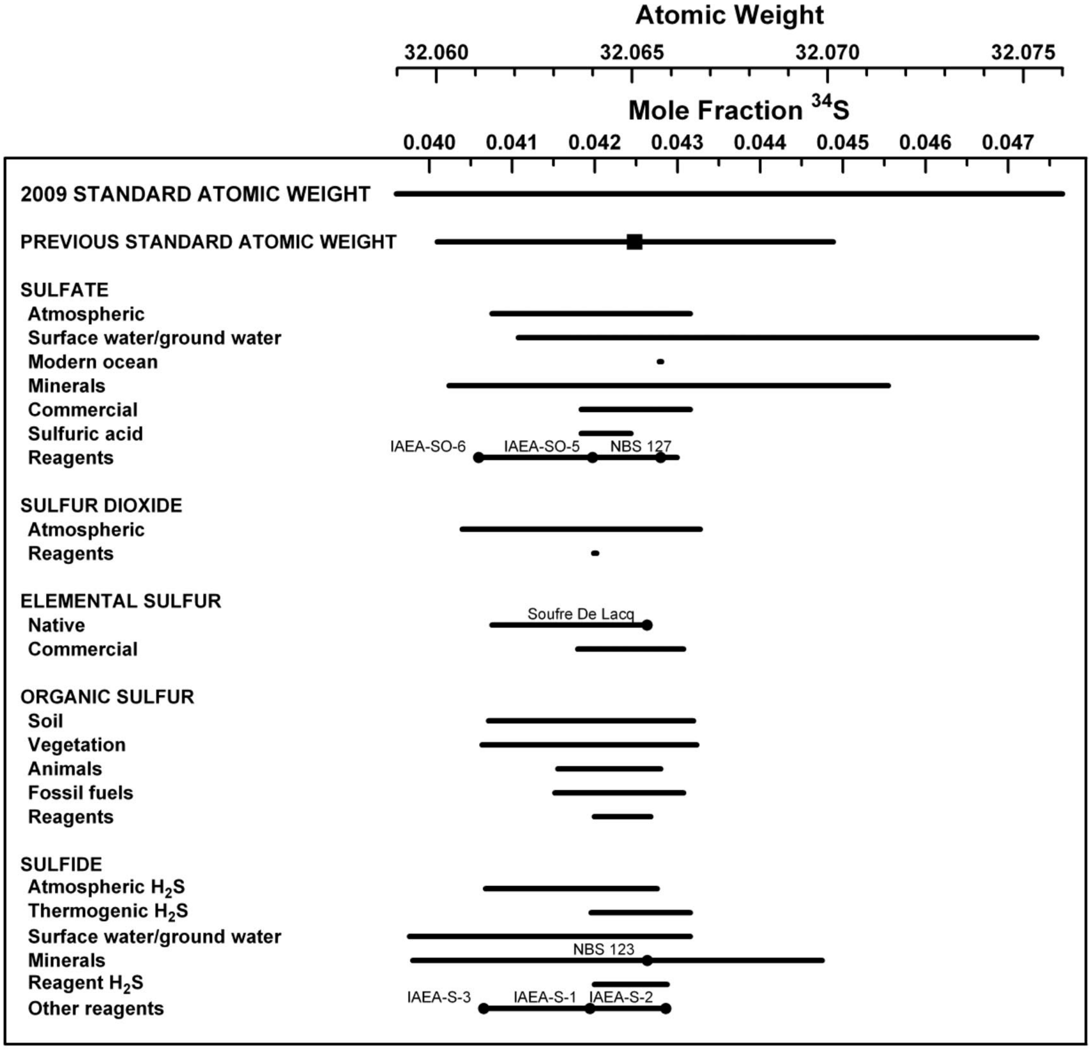

Fig. 9 Variation in atomic weight with isotopic composition of selected sulfur-bearing materials (modified from [14,15]). Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of sulfur was 32.065(5). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,54] is approximately ±0.000 02, which is more than 300 times smaller than the uncertainty of the 2007 standard atomic weight [4].

reduce the uncertainty. In the Table of Standard Atomic Weights 2007 [4], sulfur was assigned the footnotes “g” and “r”. Neither is retained in the 2009 Table of Standard Atomic Weights. Historical values of A_r(S) include [23]: 1882, 32.06; 1896, 32.07; 1903, 32.06; 1909, 32.07; 1916, 32.06; 1925, 32.064; 1931, 32.06; 1947, 32.056; 1961, 32.064(3); 1969, 32.06(1); 1983, 32.066(6).

3.9 Chlorine

The Commission has changed the recommended value for the standard atomic weight of chlorine, A_r(Cl), to the atomic-weight interval [35.446; 35.457] based on an investigation and evaluation of the effect of the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of chlorine [14,15,55]. This change in the standard atomic weight of chlorine is intended to emphasize the fact that the atomic weight of chlorine is not a constant of nature but depends upon the source of the material (Fig. 10). The lower bound of the atomic-weight interval corresponds to chlorine of perchlorate in natural nitrate fertilizer imported from the Atacama Desert, Chile [55], and the upper bound corresponds to chlorine in smectite from a Costa Rica Rift ocean drill hole [56]. The previous standard atomic-weight value A_r(Cl) = 35.453(2), recommended in 1999 [41], was based on the Commission decision to increase the uncertainty to include most Cl-bearing materials. In the Table of Standard Atomic Weights 2007 [4], chlorine was assigned the footnotes "g" "m", and "r". Only the footnote "m" is retained; this will alert readers that isotopically fractionated commercial materials might exist with atomic weights outside the interval given. Historical values of A_r(Cl) include [23]: 1882, 35.45; 1909, 35.46; 1925, 35.457; 1961, 35.453; 1969, 35.453(1).

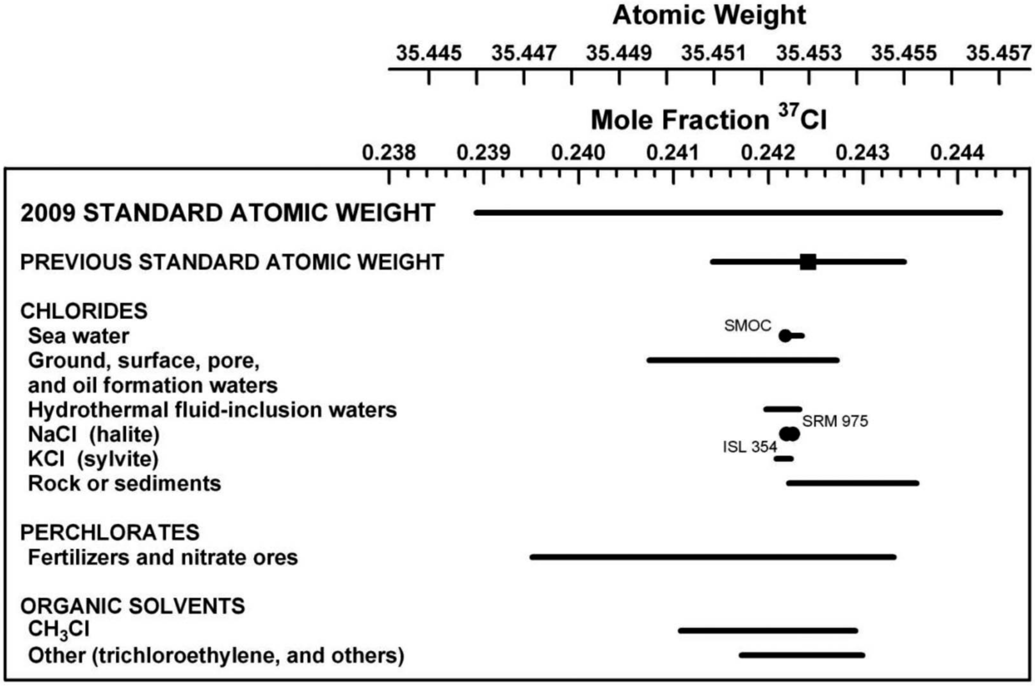

Fig. 10 Variation in atomic weight with isotopic composition of selected chlorine-bearing materials (modified from [14,15]); the data for perchlorates is from [55]. Isotopic reference materials are designated by solid black circles. The previous (2007) standard atomic weight of chlorine was 35.453(2). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,57] is approximately ±0.0009, which is one-half that of the uncertainty of the 2007 standard atomic weight [4].

3.10 Germanium

The Commission has changed the recommended value for the standard atomic weight of germanium to A_r(Ge) = 72.63(1), based on (i) a re-evaluation of lattice parameter measurements of Smakula and Kalnajs [58], density measurements of Smakula and Sils [59], and atomic-weight calculations by Smakula, Kalnajs, and Sils [60] on the basis of updated crystallographic data, and (ii) a reassessment of the mass-spectrometric measurements of Kipphardt et al. [61] and Chang et al. [62]. The previous value of A_r(Ge) = 72.64(1) was assigned by the Commission in 1999 [41], which selected the calibrated mass-spectrometric measurements of Chang et al. [62]. Historical values of A_r(Ge) include [23]: 1894, 72.3; 1897, 72.48; 1900, 72.5; 1925, 72.60; 1961, 72.59(3); 1969, 72.59(3); 1999, 72.64(1).

3.11 Thallium

The Commission has changed the recommended value for the standard atomic weight of thallium, A_r(Tl), to the atomic-weight interval [204.382; 204.385] is based on the variation in isotopic abundance in natural terrestrial materials upon the atomic weight of thallium. This change in the standard atomic weight of thallium is intended to emphasize the fact that the atomic weight of thallium is not a constant of nature but depends upon the source of the material (Fig. 11). The lower bound of the atomic-weight interval corresponds to thallium from a volcanic gas particulate sample from Kilauea, Hawaii, USA [63], and the upper bound corresponds to thallium in ferromanganese ocean sediments from the North Atlantic [64]. The previous standard atomic-weight value A_r(Tl) = 204.3833(2), recommended in 1985 [65], was based on the Commission decision to allow uncertainties other than one and three in the last place. Historical values of A_r(Tl) include [23]: 1882, 204.18; 1896, 204.15; 1903, 204.1; 1909, 204.0; 1925, 204.39; 1961, 204.37(3); 1969, 204.37(3).

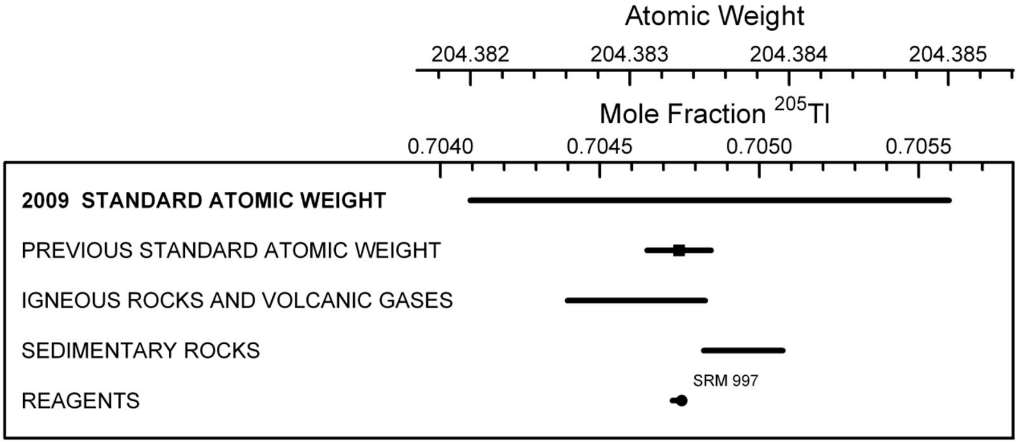

Fig. 11 Variation in atomic weight with isotopic composition of selected thallium-bearing materials (modified from [14,15] taking into account [63,64]). An isotopic reference material is designated by a solid black circle. The previous (2007) standard atomic weight of thallium was 204.3833(2). The atomic-weight uncertainty of the best measurement of isotopic abundance [7,66] is approximately ±0.000 18, which is about the same as the uncertainty of the 2007 standard atomic weight [4].

4. RELATIVE ATOMIC-MASS VALUES AND HALF-LIVES OF SELECTED RADIOACTIVE ISOTOPES

For elements that have no stable or long-lived isotopes, the data on radioactive half-lives and relative atomic-mass values for the isotopes 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 isotopes for elements numbered 113 and above in Table 3 does not imply any priority of the discovery of those elements on the part of the Commission.

Table 3 Relative atomic masses and half-lives of selected radioactive isotopes. Listing of particular isotopes for elements numbered 113 and above in this table 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 113 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) × 10^{6}	a
			98	97.9072	6.6 (10) × 10^{6}	a
			99	98.9063	2.1 (3) × 10^{5}	a
61	prometium	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 (1) × 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	7.56 (3) × 10^{4}	a
			232	232.0381	1.40 (1) × 10^{10}	a
91	protactinium	Pa	231	231.0359	3.25 (1) × 10^{4}	a
			233	233.04025	27.0 (1)	d
92	uranium	U	233	233.0396	1.590 (3) × 10^{5}	a
			234	234.0410	2.455 (6) × 10^{5}	a
			235	235.0439	7.04 (1) × 10^{8}	a
			236	236.0456	2.342 (4) × 10^{7}	a
			238	238.0508	4.468 (3) × 10^{9}	a
93	neptunium	Np	236	236.0466	1.54 (6) × 10^{5}	a
			237	237.0482	2.14 (1) × 10^{6}	a
94	plutonium	Pu	238	238.0496	87.7 (1)	a
			239	239.0522	2.410 (3) × 10^{4}	a
			240	240.0538	6.56 (1) × 10^{3}	a
			241	241.0569	14.33 (3)	a
			242	242.0587	3.75 (2) × 10^{5}	a
			244	244.0642	8.1 (1) × 10^{7}	a
95	americium	Am	241	241.0568	432.7 (6)	a
			243	243.0614	7.37 (2) × 10^{3}	a

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Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
96	curium	Cm	243	243.0614	29.1 (1)	a
			244	244.0628	18.1 (1)	a
			245	245.0655	8.48 (6) × 10^3	a
			246	246.0672	4.75 (3) × 10^3	a
			247	247.0704	1.56 (5) × 10^7	a
			248	248.0723	3.48 (6) × 10^5	a
97	berkelium	Bk	247	247.0703	1.4 (3) × 10^3	a
			249	249.0750	3.20 (3) × 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) × 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	267		~1.3	min
			271	271.133	~2	min
107	bohrium	Bh	267	267.1277	~17	s
			270		~1	min
108	hassium	Hs	270	270.1347	23	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	copernicium	Cn	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	289.187	~2.6	s
115	ununpentium	Uup	287	287.191	~0.03	s
			288	288.192	~0.09	s

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Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
116	ununhexium	Uuh	291		~18	ms
			292	292.200	~18	ms
			293		0.06 (5)	s
117	ununseptium	Uus	293		~0.01	s
			294		~0.08	s
118	ununoctium	Uuo	294		~0.89	ms

As has been the custom in the past, the Commission publishes a table of relative atomic-mass values and half-lives of selected radioactive isotopes although the Commission has no official responsibility for the dissemination of such values. There is no general agreement on which of the isotopes of 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. Atomic-mass values have been taken from the 2003 atomic-mass table [9,10]. Some of these half-lives have already been documented.

5. 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. Tables abridged to four or five significant figures are published with the hope that biennial changes will be minimal. Such constancy in these values is desirable for textbooks and numerical tables derived from atomic-weight data that do not require the precision of the full Table of Standard Atomic Weight. Standard atomic weights abridged to four and five significant figures are presented in Tables 4 and 5, respectively. Users needing an atomic-weight value that is not an interval, such as for trade and commerce, can refer to Section 6.

Table 4 Standard atomic weights 2009 abridged to four significant digits. [Using $A_r(^{12}\mathrm{C}) = 12$ as reference, where $^{12}\mathrm{C}$ is an unbound 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 $A_r(\mathrm{E})$ 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. For 10 of these elements, an atomic-weight interval is given with the symbol [*a*; *b*] to denote the set of atomic-weight values in normal materials; thus, $a \le A_r(\mathrm{E}) \le b$. The symbols *a* and *b* denote the lower and upper bounds of the interval [*a*; *b*], respectively.

Atomic number	Element name	Symbol	Atomic weight
1	hydrogen	H	[1.007; 1.009]
2	helium	He	4.003
3	lithium	Li	[6.938; 6.997]
4	beryllium	Be	9.012
5	boron	B	[10.80; 10.83]
6	carbon	C	[12.00; 12.02]
7	nitrogen	N	[14.00; 14.01]
8	oxygen	O	[15.99; 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	[28.08; 28.09]
15	phosphorus	P	30.97
16	sulfur	S	[32.05; 32.08]
17	chlorine	Cl	[35.44; 35.46]
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	72.63
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[#]

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Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
38	strontium	Sr	87.62#
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#
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	183.8
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	[204.3; 204.4]
82	lead	Pb	207.2
83	bismuth	Bi	209.0#
84	polonium*	Po	
85	astatine*	At	
86	radon*	Rn	
87	francium*	Fr	

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Table 4 (*Continued*).

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

*Element has no stable isotopes. 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.

[#] Values may differ from the atomic weights of the relevant elements in some naturally occurring samples because of a variation in the isotopic abundances of the element's stable isotopes.

Table 5 Standard atomic weights 2009 abridged to five significant digits.
[Using $A_r(^{12}C) = 12$ as reference, where ^{12}C is an unbound neutral atom in its nuclear and electronic ground state.]

The atomic weights, $A_r(E)$, of many elements vary due to variations in the abundances of their isotopes in natural terrestrial materials. For 10 elements having two or more stable isotopes, an atomic-weight interval is given with the symbol [*a*; *b*] to denote the set of atomic-weight values in normal materials; thus, $a \le A_r(E) \le b$ for element E. The symbols *a* and *b* denote the lower and upper bounds of the interval [*a*; *b*], respectively. 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). Excluding values given as atomic-weight intervals, 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 113 to 118 are provisional.

Order of atomic number

Atomic number	Element name	Symbol	Atomic weight	Footnotes	
1	hydrogen	H	[1.0078; 1.0082]	m	
2	helium	He	4.0026		
3	lithium	Li	[6.938; 6.997]	m	
4	beryllium	Be	9.0122		
5	boron	B	[10.806; 10.821]	m	
6	carbon	C	[12.009; 12.012]		
7	nitrogen	N	[14.006; 14.008]		
8	oxygen	O	[15.999; 16.000]		
9	fluorine	F	18.998		
10	neon	Ne	20.180	m	
11	sodium	Na	22.990		
12	magnesium	Mg	24.305		
13	aluminium (aluminum)	Al	26.982		
14	silicon	Si	[28.084; 28.086]		
15	phosphorus	P	30.974		
16	sulfur	S	[32.059; 32.076]		
17	chlorine	Cl	[35.446; 35.457]	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		

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Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
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	72.63	
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
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
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	

(*continues on next page*)

Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
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; 204.39]	
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		
107	bohrium*	Bh		
108	hassium*	Hs		
109	meitnerium*	Mt		
110	darmstadtium*	Ds		
111	roentgenium*	Rg		
112	copernicium *	Cn		
113	ununtrium*	Uut		
114	ununquadium*	Uuq		
115	ununpentium*	Uup		

(*continues on next page*)

Table 5 (*Continued*).

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

*Element has no stable isotopes. 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.

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.

6. CONVENTIONAL ATOMIC-WEIGHT VALUES FOR SELECTED ELEMENTS

At its 2009 meeting in Vienna, the Commission reviewed recommendations from the task group of the IUPAC project "Assessment of fundamental understanding of isotopic abundances and atomic weights of the chemical elements" [8]. In addition to recommending that intervals be included in the 2009 Table of Standard Atomic Weights for elements having two or more isotopes when the variation in atomic weights in natural terrestrial occurrences exceeds that of the measurement uncertainty of the standard atomic weight determined from a best measurement of isotopic abundances, the task group recognized that some users may need a representative value for an element having an atomic-weight interval, such as for trade and commerce. Conventional atomic-weight values are conventional quantity values [21], and they are provided in Table 6 for these users. These conventional values have no uncertainty values associated with them. They have been selected so that most or all natural terrestrial atomic-weight variation is covered in an interval of plus or minus one in the last digit. For example, the conventional atomic-weight value of boron, 10.81, is selected to account for boron-bearing materials with atomic-weight values between 10.80 and 10.82, which is the majority of boron-bearing substances (Fig. 5).

Table 6 Conventional atomic weights 2009.

[For users needing an atomic-weight value for an unspecified sample, such as for trade and commerce, the following conventional values are provided.]

Element name	Symbol	Atomic number	Reference atomic weight
boron	B	5	10.81
carbon	C	6	12.011
chlorine	Cl	17	35.45
hydrogen	H	1	1.008
lithium	Li	3	6.94
nitrogen	N	7	14.007
oxygen	O	8	15.999
silicon	Si	14	28.085
sulfur	S	16	32.06
thallium	Tl	81	204.38

7. MEMBERSHIP OF SPONSORING BODIES

Membership of the IUPAC 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*:** R. Gonfiantini (Italy); ***Secretary*:** M. Wieser (Canada); ***Titular Members*:** M. Berglund (Belgium); M. Gröning (Austria); T. Walczyk (Singapore); S. Yoneda (Japan); ***Associate Members*:** W. A. Brand (Germany); T. Hirata (Japan); R. Schoenberg (Norway); X. K. Zhu (China/Beijing); ***National Representatives*:** J. K. Böhlke (USA); P. De Bièvre (Belgium); J. R. de Laeter (Australia).

The Commission on Isotopic Abundances and Atomic Weights notes the death of two former members of the Commission. Etienne Roth, 5 June 1922 to 19 March 2009, was an expert in both radioactive and stable isotopes. Etienne, a long-time contributor to IUPAC, was a Titular and Associate member of the Commission from 1967 to 1979, and he served as its chairman from 1975 to 1979. Kevin J. R. Rosman, 10 February 1943 to 23 March 2009. Kevin was a Titular and Associate Member of the Commission between 1985 and 1996. Under Kevin's leadership during the late 1980s and the 1990s, the Commission's Table of Isotopic Composition of the Elements was updated conscientiously and published.

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