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Atomic weights of the elements 2011 (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 five elements. The atomic weight of bromine has changed from 79.904(1) to the interval [79.901, 79.907], germanium from 72.63(1) to 72.630(8), indium from 114.818(3) to 114.818(1), magnesium from 24.3050(6) to the interval [24.304, 24.307], and mercury from 200.59(2) to 200.592(3). For bromine and magnesium, assignment of intervals for the new standard atomic weights reflects the common occurrence of variations in the atomic weights of those elements in normal terrestrial materials.

Keywords: atomic-weight intervals; atomic-weight ranges; bromine; conventional atomic-weight values; germanium; half-lives; indium; IUPAC Inorganic Chemistry Division; magnesium; mercury; standard atomic weights.

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1. INTRODUCTION

Comprehensive tables of recommended atomic-weight values for use in science, industry, and commerce began with F. W. Clarke's publication of his recalculation of the atomic weights in 1882. In 1892, the American Chemical Society appointed Clarke as a permanent one-man committee to report on a standard table of atomic weights for acceptance by the society, and he reported annually from 1893 until 1913, when he asked to be relieved of this responsibility. In 1897, the Deutsche Chemische Gesellschaft appointed a working committee to report on atomic weights. They published reports on best values and also issued an invitation to other chemistry organizations to appoint delegates to an international committee for atomic weights. The international committee's first report for 1901 was published in *Chemische Berichte* in 1902, and this committee continued to report annually until 1921. This committee joined the International Association of Chemical Societies in September 1913, until it was dissolved in 1919. The committee then joined the International Union of Pure and Applied Chemistry (IUPAC) in June 1920. IUPAC published the new committee's first table of atomic weights in 1925. After reorganization, the international committee began to publish annual reports in 1931 [1].

Atomic-weight values originally were considered to be constants of nature and, as such, did not have any associated uncertainties. However, in the 1951 report, the committee added a footnote to sulfur indicating that a variation factor (0.003) should be attached to its atomic-weight value to account for atomic-weight variations in naturally occurring sources of sulfur. In 1961, the committee added footnotes to account for variations in atomic weights in naturally occurring sources of a number of elements, as well as experimental measurement uncertainties. By 1967, IUPAC's Commission on Atomic Weights, as it was known then, recognized that the standard atomic-weight uncertainties of some elements (H, B, C, O, Si, S, and Cu) could not be reduced because of variations in the mole fractions of their isotopes in normal materials [2], including some chemical reagents [3]. By a "normal" material, the IUPAC Commission on Isotopic Abundances and Atomic Weights (hereafter termed the Commission) means material from a terrestrial source that satisfies the following criteria:

> "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." [4,5]

With improvements in analytical instrumentation during the last three decades, the number of elements with two or more isotopes with documented 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 [6]. These elements were given footnote "r" in the IUPAC Table of Standard Atomic Weights to indicate that a range in isotopic composition of normal material prevents a more precise standard-atomic-weight value from being given. Until the publication of the 2009 Table of Standard Atomic Weights, the Commission provided a single atomic-weight value for each element (with at least one stable isotope) along with an estimated symmetrical and expanded uncertainty. These uncertainties were always estimated by the Commission through evaluation of all the relevant published literature such that any user of the atomic-weight data would, with high probability, find the atomic weight of any element in any normal sample to be in the range indicated by the uncertainty for the recommended standard atomic weight. These values thus correspond to expanded uncertainties as now defined by the International Organization for Standards (ISO) [7], and they are generally consistent with those calculated by orthodox statistical procedures from the isotopic abundances listed in column 9 of the Table of Isotopic Composition of the Elements [8]. Beginning with the 2009 Table of Standard Atomic Weights [9], the Commission highlighted the existence of atomic-weight variations for some elements by reporting atomic-weight intervals rather than single values with expanded uncertainties. The upper and lower bounds of the atomic-weight interval for a given element define the interval within which the atomic-weight value for any given sample of normal material may be found (see Section 1.4). 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 [4,5,10,11].

Most recently, the Commission met at the University of Calgary, Canada under the chairmanship of Dr. W. A. Brand from 27 to 28 July 2011, prior to the 46th IUPAC General Assembly in San Juan, Puerto Rico. At this meeting, the Commission reviewed recommendations of its Subcommittee on Isotopic Abundance Measurements (SIAM), suggesting changes in the standard atomic weights of some elements based on review of published data.

1.1 Atomic weight of an element

The **atomic mass**, m_a, of an unbound neutral atom of carbon-12, $m_a(^{12}\mathrm{C})$, in its nuclear and electronic ground states is 12 u exactly, where u is the unified atomic mass unit. The **atomic weight** (also called the relative atomic mass) of isotope $^i\mathrm{E}$ of element E, symbol $A_r(^i\mathrm{E})$, in material P is

$$A_r(^i\mathrm{E})_\mathrm{P} = \frac{m_a(^i\mathrm{E})_\mathrm{P}}{\frac{1}{12}\, m_a(^{12}\mathrm{C})} = \frac{m_a(^i\mathrm{E})_\mathrm{P}}{\mathrm{u}}$$

Thus, the atomic mass of $^{12}\mathrm{C}$ is 12 u, and the atomic weight of $^{12}\mathrm{C}$ is 12 exactly. All other atomic weight values are ratios to the $^{12}\mathrm{C}$ standard value and thus are dimensionless numbers. The atomic weight of element E, $A_r(\mathrm{E})$, in a material P is determined from the relation

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

where $x(^i\mathrm{E})_\mathrm{P}$ is the mole fraction of isotope $^i\mathrm{E}$ in material P (also called the isotopic abundance). The summation is over all stable isotopes of the element plus selected radioactive isotopes (having relatively long half-lives and characteristic terrestrial isotopic compositions) of the element.

The atomic weight, $A_r(\mathrm{E})$, of element E in a material 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 material. In contrast to the atomic weight of an element in any given material, the *standard atomic weight* is a quantity that represents the atomic weights of an element in normal terrestrial materials and, therefore, must be given with larger uncertainty for some elements than the measured atomic weight in any given material. Isotopes contributing to the determination of the atomic weight of an element include (1) all stable isotopes (not known to be radioactive), of which there are 256, and (2) selected radioactive isotopes that have relatively long half-lives and characteristic terrestrial isotopic compositions, of which there are 32. A radioactive isotope of an element is said to have a *characteristic terrestrial isotopic composition* [12] if it contributes significantly and reproducibly to the determination of the standard atomic weight of the element in normal materials. There are 19 elements that have only one stable isotope (Be, F, Na, Al, P, Sc, Mn, Co, As, Y, Nb, Rh, I, Cs, Pr, Tb, Ho, Tm, and Au). The standard atomic weight of each of these elements is derived from the atomic mass of its single stable isotope with expansion of the reported atomic-mass uncertainty to minimize future changes in the atomic weights. For elements in normal materials with no stable isotope or with no radioactive isotope with a characteristic terrestrial isotopic composition, no standard atomic weight can be determined and no value is provided in the Table of Standard Atomic Weights for these elements. The majority of the elements have two or more stable isotopes, in which case the atomic weight of an element in a material is the abundance-weighted sum of the atomic masses of its isotopes.

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 increasing accuracy (decreasing measurement uncertainty) by means of mass spectrometry. As a result, the uncertainty in atomic-weight measurements, $U[A_r(\mathrm{E})]$, 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 is defined as a set of analyses of the isotope-amount ratio or isotope-number ratio 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, interferences among 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 normal 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 by national or international measurement institutes, or to isotopically unfractionated representatives of homogeneous terrestrial materials.

The Commission has determined that new, calibrated isotopic-composition measurements could improve substantially the standard atomic-weight values of a number of elements that have relatively large uncertainties. Such elements include Gd, Hf, Pd, and Sm.

1.3 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 on Natural Isotopic Fractionation and through subsequent IUPAC projects.

All known elements can be categorized according to the following constraints on their standard atomic weights:

1. Elements with no stable isotope and with no radioactive isotope having a characteristic terrestrial isotopic composition in normal materials (e.g., radon). No standard atomic weight can be determined, 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 [13–15].
3. Elements with two or more isotopes having no documented evidence of variation in atomic weight for normal materials, or elements that have not been evaluated for variation in isotopic composition by an IUPAC project (e.g., tungsten).
4. Elements with two or more isotopes having known variations in atomic weight in normal materials, but these variations do not exceed the evaluated measurement uncertainty of the atomic weight derived from the best measurement of the isotopic abundances of an element (e.g., molybdenum).

5. Elements with two or more isotopes having known variations in atomic weight in normal materials that exceed the uncertainty of the atomic weight derived from a best measurement of isotopic abundances, but not yet assigned an atomic-weight interval by the Commission (e.g., copper).
6. Elements with two or more isotopes having known variations in atomic weight in normal materials that exceed the uncertainty of the atomic weight derived from a best measurement of isotopic abundances and having upper and lower atomic-weight bounds determined by the Commission from evaluated, peer-reviewed, published data (e.g., carbon) (Fig. 1).

Elements in category 3 may enter category 4 as more accurate isotopic-abundance measurements are published. Similarly, elements in category 4 can advance to category 5 as best-measurement results improve. Elements in category 5 can advance to category 6 as the Commission completes evaluations and assigns intervals. The Commission uses the footnote "r" to identify elements in category 5 for which the standard-atomic-weight uncertainty has been expanded to account for known atomic-weight variability. Graphical plots of isotopic-abundance variation and atomic-weight variation were published previously for 15 such elements: H, Li, B, C, N, O, Mg, Si, S, Cl, Ca, Cr, Fe, Cu, and Tl [16,17]. The Commission uses the footnote "g" to identify chemical elements for which the recommended standard atomic weight and its associated uncertainty do not include all known variations. For example, some elements are anomalously enriched in fissionogenic or nucleogenic isotopes at the Oklo natural nuclear reactor site in Gabon, Africa, and their atomic weights in those materials are not included in the determination of the standard atomic weight. For elements in category 3 to 6 elements, the Commission uses the footnote "m" to identify those 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. Minor periodic changes to the standard-atomic-weight values and uncertainties result from improved measurements of the atomic masses, and these changes primarily affect category 2 elements.

1.4 Atomic-weight intervals

Atomic weights calculated from published variations in isotopic compositions for some elements can span relatively large intervals. For example, the atomic weight of carbon in normal materials spans the interval from 12.0096 to 12.0116 (Fig. 1), whereas the uncertainty of the atomic weight calculated from the best measurement of the isotopic abundance of carbon is approximately 30 times smaller [8,18]; $A_r(\mathrm{C}) = 12.011\,09(3)$. The span of atomic-weight values in normal materials is termed the interval. The interval $[a, b]$ is the set of values x for which $a \leq x \leq b$, where $b > a$ and where a and b are the lower and upper bounds, respectively [19]. 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, $b - a$ [19]; thus, the range of the atomic-weight interval of carbon is calculated as 12.0116 – 12.0096 = 0.0020. The interval designation does not imply any statistical distribution of atomic-weight values between the lower and upper bounds (e.g., the mean of a and b is not necessarily the most likely value). Similarly, the interval does not convey a simple statistical representation of uncertainty. In the 2009 Table of Standard Atomic Weights, the interval was signified by $[a; b]$. With the 2012 correction of *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* [19], the symbol for expressing an interval in English language publications has changed from $[a; b]$ to $[a, b]$.

The lower bound of an atomic-weight interval is determined from the lowest atomic weight determined by the Commission's evaluations, and it takes into account the uncertainty of the measurement. Commonly, an isotope-delta measurement is the basis for the determination of the bound [15,16]. In

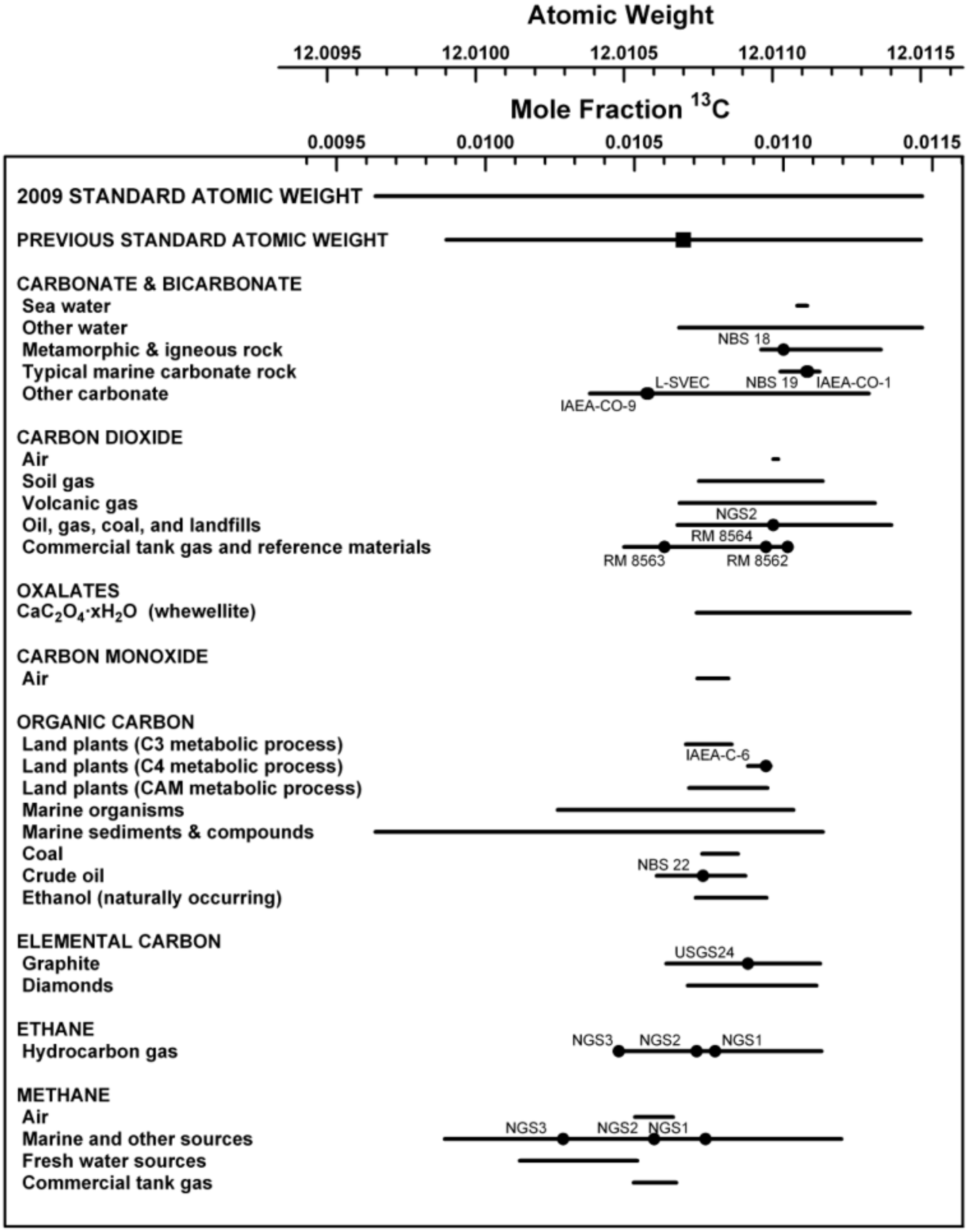

Fig. 1 Variation in atomic weight with isotopic composition of selected carbon-bearing materials (modified from [16,17]). Isotopic reference materials are designated by solid black circles. The 2009 standard atomic weight of carbon is expressed as an interval [12.0096, 12.0116] [9]. The previous (2007) standard atomic weight of carbon [6] was 12.0107(8). The atomic-weight uncertainty of the "best measurement" of isotopic abundance [16,17] is approximately ±0.000 027, which is about 30 times smaller than the uncertainty of the 2007 standard atomic weight [6].

addition to the uncertainty in the isotope-delta value [20], the uncertainty in the atomic weight of the material anchoring the isotope-delta scale also must be taken into account. The latter is the uncertainty in relating a delta scale to an atomic-weight scale [16,17]. If material P is the normal material having the lowest atomic weight of element E, then

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

where $U[A_r(\text{E})]_\text{P}$ is the combined uncertainty that incorporates the uncertainty in the measurement of the delta value of material P and the uncertainty in relating the delta-value scale to the atomic-weight scale. For example, consider the lower bound for carbon. The material with the lowest measured ^{13}C abundance is crocetane (2,6,11,15-tetramethylhexadecane), produced at cold seeps of the eastern Aleutian subduction zone [21]. For this material, $A_r(\text{C}) = 12.009\,662$, where the atomic weight is determined from an isotope-delta value [16,17]. 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 $U[A_r(\text{E})]_\text{P} = (0.000\,003^2 + 0.000\,027^2)^{1/2} = 0.000\,027$ 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 material P with the highest measured atomic weight.

$$\text{upper bound} = \text{highest } A_r(\text{E})_\text{P} + U[A_r(\text{E})]_\text{P}$$

For the example of carbon, the material with the highest ^{13}C-abundance fraction is deep-sea pore water, and it has an atomic-weight value of 12.011 505. The component of uncertainty in the atomic-weight value of this material attributed 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 digits 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 significant figures
15.999	16.000	Table of Standard Atomic Weights Abridged to Five Significant Digits
15.99	16.00	Table of Standard Atomic Weights Abridged to Four Significant Digits

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, $a \le A_r(\text{E}) \le b$.

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*. For example, $A_r(\mathrm{C})$ = [12.0096, 12.0116] and should not be expressed as $A_r(\mathrm{C})$ = 12.0106(48).
3. The atomic-weight interval encompasses atomic-weight values of all normal materials.
4. The atomic-weight interval is the standard atomic weight.
5. The atomic-weight interval and range should not be confused. The atomic-weight range is $b - a$, 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 digits in the lower and upper bounds are adjusted so that uncertainty in either of the isotope-delta measurements or in the uncertainty relating the delta scale to the atomic-weight scale do not impact the lower and upper bounds.
9. The number of significant digits 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 the Commission following completion of an IUPAC project reviewing the published literature for peer-reviewed, isotopic-abundance data.
13. If the standard-atomic-weight uncertainty for an element has been expanded because of reported variation in isotopic composition in normal materials, but the Commission has not assigned an interval, a footnote “r” is retained in the Table of Standard Atomic Weights until the Commission completes an evaluation and determines lower and upper bounds from published data.

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

The Table of Standard Atomic Weights 2011 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 normal terrestrial materials as well as 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 2011 lists atomic-weight intervals for the standard atomic weights of 12 such elements (B, Br, C, Cl, H, Li, Mg, N, O, S, Si, and Tl). Graphical plots showing isotopic abundances and atomic weights of various specimens are provided for C, Br, and Mg in this report. Similar graphical plots for B, Cl, H, Li, N, O, S, Si, and Tl may be found in the Table of Standard Atomic Weights 2009 [6].

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. 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 atomic-weight values of normal materials.

Table 1 Standard atomic weights 2011.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights, $A_r(E)$, of many elements vary because of variations in the abundances of their isotopes in normal materials. For 12 such elements, an atomic-weight interval is given with the symbol [*a*, *b*] to denote the set of atomic-weight values in normal materials; thus, $a \leq A_r(E) \leq b$ for element E. The symbols *a* and *b* denote the bounds of the interval [*a*, *b*]. If a more accurate $A_r(E)$ value for a specific material is required, it should be determined. For 72 elements, $A_r(E)$ values and their evaluated uncertainties (in parentheses, following the last significant digit to which they are attributed) are given. Names of elements with atomic number 113, 115, 117, and 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	Standard 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 in ref. [8]	m
bromine	Br	35	[79.901, 79.907]	6/2	
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]	6/1	
cerium	Ce	58	140.116(1)		g
chlorine	Cl	17	[35.446, 35.457]	6/10 in ref. [8]	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			
flerovium*	Fl	114			
fluorine	F	9	18.998 4032(5)		
francium*	Fr	87			
gadolinium	Gd	64	157.25(3)		g
gallium	Ga	31	69.723(1)		

(*continues on next page*)

Table 1 (*Continued*).

Alphabetic order in English					
Element name	Symbol	Atomic number	Standard atomic weight	See also Table/Figure	Footnotes
germanium	Ge	32	72.630(8)		
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 in ref. [8]	m
indium	In	49	114.818(1)		
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 in ref. [8]	m
livermorium*	Lv	116			
lutetium	Lu	71	174.9668(1)		g
magnesium	Mg	12	[24.304, 24.307]	6/3	
manganese	Mn	25	54.938 045(5)		
meitnerium*	Mt	109			
mendelevium*	Md	101			
mercury	Hg	80	200.592(3)		
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 in ref. [8]	
nobelium*	No	102			
osmium	Os	76	190.23(3)		g
oxygen	O	8	[15.999 03, 15.999 77]	6/7 in ref. [8]	
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)		

(*continues on next page*)

Table 1 (*Continued*).

Alphabetic order in English					
Element name	Symbol	Atomic number	Standard atomic weight	See also Table/Figure	Footnotes
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 in ref. [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 in ref. [8]	
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 in ref. [8]	
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)		
ununoctium*	Uuo	118			
ununpentium*	Uup	115			
ununtrium*	Uut	113			
ununseptium*	Uus	117			
uranium*	U	92	238.028 91(3)		g m
vanadium	V	23	50.9415(1)		
xenon	Xe	54	131.293(6)		g m
ytterbium	Yb	70	173.054(5)		g
yttrium	Y	39	88.905 85(2)		
zinc	Zn	30	65.38(2)		r
zirconium	Zr	40	91.224(2)		g

*Element has no stable isotopes. One or more representative isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, four such elements (Bi, Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these elements, standard atomic weights are tabulated.

g Geological materials 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 materials 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 2011.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights, $A_r(E)$, of many elements vary because of variations in the abundances of their isotopes in normal materials. For 12 such 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*]. If a more accurate $A_r(E)$ value for a specific material is required, it should be determined. For 72 elements, $A_r(E)$ values and their evaluated uncertainties (in parentheses, following the last significant digit to which they are attributed) are given. Names of elements with atomic number 113, 115, 117, and 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 in ref. [8]	m
2	helium	He	4.002 602(2)		g r
3	lithium	Li	[6.938, 6.997]	6/4 in ref. [8]	m
4	beryllium	Be	9.012 182(3)		
5	boron	B	[10.806, 10.821]	6/5 in ref. [8]	m
6	carbon	C	[12.0096, 12.0116]	6/1	
7	nitrogen	N	[14.006 43, 14.007 28]	6/6 in ref. [8]	
8	oxygen	O	[15.999 03, 15.999 77]	6/7 in ref. [8]	
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	[24.304, 24.307]	6/3	
13	aluminium (aluminum)	Al	26.981 5386(8)		
14	silicon	Si	[28.084, 28.086]	6/8 in ref. [8]	
15	phosphorus	P	30.973 762(2)		
16	sulfur	S	[32.059, 32.076]	6/9 in ref. [8]	
17	chlorine	Cl	[35.446, 35.457]	6/10 in ref. [8]	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	72.630(8)		
33	arsenic	As	74.921 60(2)		
34	selenium	Se	78.96(3)		r
35	bromine	Br	[79.901, 79.907]	6/2	
36	krypton	Kr	83.798(2)		g m
37	rubidium	Rb	85.4678(3)		g
38	strontium	Sr	87.62(1)		g r

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number					
Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
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(1)		
50	tin	Sn	118.710(7)		g
51	antimony	Sb	121.760(1)		g
52	tellurium	Te	127.60(3)		g
53	iodine	I	126.904 47(3)		
54	xenon	Xe	131.293(6)		g m
55	caesium (cesium)	Cs	132.905 4519(2)		
56	barium	Ba	137.327(7)		
57	lanthanum	La	138.905 47(7)		g
58	cerium	Ce	140.116(1)		g
59	praseodymium	Pr	140.907 65(2)		
60	neodymium	Nd	144.242(3)		g
61	promethium*	Pm			
62	samarium	Sm	150.36(2)		g
63	europium	Eu	151.964(1)		g
64	gadolinium	Gd	157.25(3)		g
65	terbium	Tb	158.925 35(2)		
66	dysprosium	Dy	162.500(1)		g
67	holmium	Ho	164.930 32(2)		
68	erbium	Er	167.259(3)		g
69	thulium	Tm	168.934 21(2)		
70	ytterbium	Yb	173.054(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	200.592(3)		
81	thallium	Tl	[204.382, 204.385]	6/11 in ref. [8]	
82	lead	Pb	207.2(1)		g r
83	bismuth*	Bi	208.980 40(1)		
84	polonium*	Po			
85	astatine*	At			

(*continues on next page*)

Table 2 (*Continued*).

Order of atomic number					
Atomic number	Element name	Symbol	Atomic weight	See also Table/Figure	Footnotes
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			
110	darmstadtium*	Ds			
111	roentgenium*	Rg			
112	copernicium*	Cn			
113	ununtrium*	Uut			
114	flerovium*	Fl			
115	ununpentium*	Uup			
116	livermorium*	Lv			
117	ununseptium*	Uus			
118	ununoctium*	Uuo			

*Element has no stable isotopes. One or more representative isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, four such elements (Bi, Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these elements, standard atomic weights are tabulated.

g Geological materials 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 materials 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 $A_r(\mathrm{E})$ being given; the tabulated $A_r(\mathrm{E})$ value and uncertainty should be applicable to normal material.

For each element 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 [22] and subsequent

Commission publications. Values before the formation of the International Committee on Atomic Weights in 1900 come from [23].

Provisional names and symbols given in Tables 1 and 2 for elements with atomic numbers 113 to 118 are systematic and based on the atomic numbers of the elements as recommended by the IUPAC publication *Nomenclature of Inorganic Chemistry* [24]. Each systematic name and symbol will be replaced by a permanent name approved by IUPAC after 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 combined 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”.

3. COMMENTS ON ATOMIC WEIGHTS AND ANNOTATIONS OF SELECTED ELEMENTS

Brief descriptions of the changes to the standard atomic weights resulting from the Commission meeting in 2011 are provided below.

3.1 Bromine

The Commission has changed the recommended value for the standard atomic weight of bromine, $A_r(\text{Br})$, from 79.904(1) to the atomic-weight interval [79.901, 79.907] based on an evaluation of the effect of variation in isotopic abundances in normal materials upon the atomic weight of bromine. This change is intended to emphasize the fact that the atomic weight of bromine is not a constant of nature, but depends upon the source of the material (Fig. 2). The standard atomic weight was determined by combining (1) the best calibrated isotope-ratio measurement of bromine in SRM977 NaBr isotopic reference material [25,26], formerly known as NBS106 [25], (2) the relative isotope-ratio difference between SRM977 and bromide in ocean water [27], and (3) the relative isotope-ratio differences between other materials and ocean-water bromide [2,28]. Bromide in ocean water is isotopically homogeneous and serves as the international measurement standard for bromine [26], standard mean ocean bromide (SMOB). Bromine relative isotope-ratio differences, also called bromine isotope delta values, have been reported with the symbol $\delta^{81}\text{Br}$ [26–28] and are defined by the relation [20]

$$\delta^{81}\text{Br} = \frac{N\left(^{81}\text{Br}\right)_\text{P}\Big/N\left(^{79}\text{Br}\right)_\text{P} - N\left(^{81}\text{Br}\right)_\text{SMOB}\Big/N\left(^{79}\text{Br}\right)_\text{SMOB}}{N\left(^{81}\text{Br}\right)_\text{SMOB}\Big/N\left(^{79}\text{Br}\right)_\text{SMOB}}$$

where $N(^{81}\text{Br})_\text{P}$ and $N(^{79}\text{Br})_\text{P}$ are the numbers of atoms of the two isotopes ^{81}Br and ^{79}Br in material P and equivalent parameters follow for bromine in SMOB. The minimum and maximum $\delta^{81}\text{Br}$ values of saline waters and salt deposits (Fig. 1) are –0.8 and +3.35 ‰ relative to SMOB [27]. The minimum and maximum $\delta^{81}\text{Br}$ values of brominated organic compounds (Fig. 2) are –4.3 and +0.2 ‰ relative to SMOB [28]. The minimum and maximum $\delta^{81}\text{Br}$ values of elemental bromine (Fig. 1), calculated from isotope-ratio measurements of [25], are –0.84 and +0.36 ‰ relative to SMOB, but measurement uncertainties were sufficiently large that isotopic abundance variations were not conclusively demonstrated [25]. The lower bound of the standard atomic weight corresponds to bromine in a brominated benzene reagent [28], and the upper bound corresponds to dissolved bromide in saline groundwater from Siberia [27]. The previous standard atomic-weight value $A_r(\text{Br}) = 79.904(1)$, recommended by the Commission in 1965 and published in “Atomic weights of the elements 1967” [2], was based on the measurements

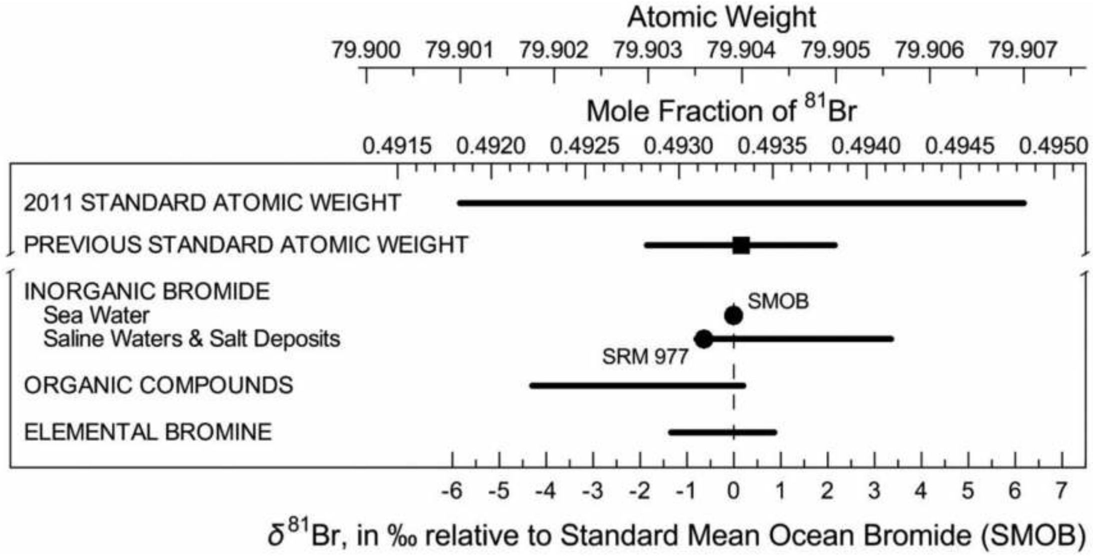

Fig. 2 Variation in isotopic composition and atomic weight of bromine in selected bromine-bearing materials. Data for inorganic bromide are from [25–27]. Data for organic compounds are from [28]. Data for elemental bromine are from [25]. Isotopic reference materials are designated by solid black circles. The previous (1965 to 2009) standard atomic weight of bromine was 79.904(1). The atomic-weight uncertainty of the best measurement of isotopic abundance [8] is approximately ±0.0005, which is about four times smaller than the uncertainty of the 2009 standard atomic weight [9] and 12 times smaller than the 2011 standard-atomic-weight interval. The δ^{81}Br scale and the ^{81}Br mole-fraction scale were matched using data from [25,26], and the uncertainty in placement of the atomic-weight scale and the ^{81}Br mole-fraction scale relative to the δ^{81}Br scale is equivalent to ±1.1 ‰.

of Catanzaro et al. [25], who found no evidence for variations in isotopic abundance in normal materials. Previous historical values of A_r(Br) include [22]: 1882, 79.95; 1903, 79.96; 1909, 79.92; 1925, 79.916; 1961, 79.909; and 1965, 79.904.

3.2 Germanium

The Commission has changed the recommended value for the standard atomic weight of germanium, A_r(Ge), from 72.63(1) to 72.630(8) based on an evaluation published by Yang and Meija [29]. A log-linear regression mass-bias correction using NIST SRM 994 gallium isotopic reference material enabled an improvement in the uncertainty of the atomic-weight value compared to the previous value of A_r(Ge) = 72.63(1), assigned by the Commission in 2009 [9]. Historical values of A_r(Ge) include [22]: 1894, 72.3; 1897, 72.48; 1900, 72.5; 1925, 72.60; 1961, 72.59; 1969, 72.59(3); 1999, 72.64(1); 2009, 72.63(1).

3.3 Indium

The Commission has changed the recommended value for the standard atomic weight of indium, A_r(In), from 114.818(3) to 114.818(1) based on a partially calibrated mass-spectrometric measurement by Yang et al. [30]. The authors employed a novel approach, which enables the comparison of isotopic compositions between elements, in this case to combine the measurements of the isotopic compositions of silver and indium along with the silver isotopic composition of NIST SRM 978a. Although the comparison of isotopic compositions of elements is common in science, it usually invokes the assumption that both elements have the same behavior in mass spectrometry, an assumption that is known to be false. The work of Yang et al. obviates the need for such an assumption and produces an atomic-weight value of indium traceable directly to the atomic weight of silver, thus reviving a network of relationships among the isotopic compositions of various elements, which, incidentally, was one of the most salient features of the "Harvard method" for which T. W. Richards was awarded the Nobel Prize for Chemistry in 1914. Historical values of A_r(In) include [22]: 1882, 113.66; 1894, 113.7; 1897, 113.85; 1900, 114; 1905, 115; 1909, 114.8; 1934, 114.76; 1955, 114.78; 1969, 114.82(1); 1991, 114.818(3).

3.4 Magnesium

The Commission has changed the recommended value for the standard atomic weight of magnesium, A_r(Mg), from 24.3050(6) to the atomic-weight interval [24.304, 24.307] based on an evaluation of the effect of variation in isotopic abundances in normal materials upon the atomic weight of magnesium. This change is intended to emphasize the fact that the atomic weight of magnesium is not a constant of nature, but depends upon the source of the material (Fig. 3). The standard atomic weight was determined by combining (1) the best calibrated isotope-ratio measurement of magnesium in DSM3 isotopic reference material [31], a mono-elemental nitric solution of magnesium, and (2) the relative isotope-ratio differences between other magnesium-bearing materials and DSM3 [32–38]. Bizzarro et al. [31] are to be congratulated for their high-precision isotopic abundance measurement of DSM3 using a double spike for correction of instrumental bias and high-resolution multicollector inductively coupled plasma-mass spectrometry. Their measurement has been accepted as a "best measurement" of isotopic abundance. The isotope ratios recommended for acceptance as a best measurement are $N(^{25}\text{Mg})/N(^{24}\text{Mg}) = 0.126\,91(11)$ and $N(^{26}\text{Mg})/N(^{24}\text{Mg}) = 0.139\,69(15)$. The isotopic abundance values to be published as a best measurement in the next Table of Isotopic Compositions of the Elements are $x(^{24}\text{Mg}) = 0.7895(1)$, $x(^{25}\text{Mg}) = 0.100\,20(8)$, and $x(^{26}\text{Mg}) = 0.1103(1)$.

Magnesium relative isotope-ratio differences, also called magnesium isotope-delta values, have been reported with the symbol δ^{26}Mg [31–38] and are defined by the relation [28]

$$\delta^{26}\text{Mg} = \frac{N\left(^{26}\text{Mg}\right)_\text{P} / N\left(^{24}\text{Mg}\right)_\text{P} - N\left(^{26}\text{Mg}\right)_\text{Std} / N\left(^{24}\text{Mg}\right)_\text{Std}}{N\left(^{26}\text{Mg}\right)_\text{Std} / N\left(^{24}\text{Mg}\right)_\text{Std}}$$

where $N(^{26}\text{Mg})_\text{P}$ and $N(^{24}\text{Mg})_\text{P}$ are the numbers of atoms of the two isotopes ^{26}Mg and ^{24}Mg in material P and equivalent parameters follow for magnesium in the standard (Std). Many of the δ^{26}Mg measurements reported herein were made using DSM3 as the standard. However, the Commission does not recommend DSM3 as an international measurement standard for δ^{26}Mg measurements because a supply for the next 5–10 years is not readily available to laboratories worldwide.

The lower bound of the standard atomic weight corresponds to magnesium in planktonic foraminifer (*Globigerinoides sacculifer*) having a δ^{26}Mg value of –5.57 ‰ relative to DSM3 [32]. The upper bound of the standard atomic weight corresponds to magnesium in a specimen of olivine having a δ^{26}Mg value of +1.03 ‰ relative to DSM3 [33]. The previous standard atomic-weight value A_r(Mg) = 24.3050(6), recommended by the Commission in 1985 and published in "Atomic weights of the elements 1967" [2], was based on the "absolute" isotopic abundance measurements of Catanzaro et al. [39], and Catanzaro and Murphy [40] found no evidence for variations in isotopic abundance in normal materials. Previous historical values of A_r(Mg) include [20]: 1882, 24.01; 1894, 24.3; 1896, 24.29; 1897, 24.28; 1900, 24.3; 1903, 24.36; 1909, 24.32; 1961, 24.312; 1967, 24.305; 1969, 24.305(1); and 1985, 24.3050(6).

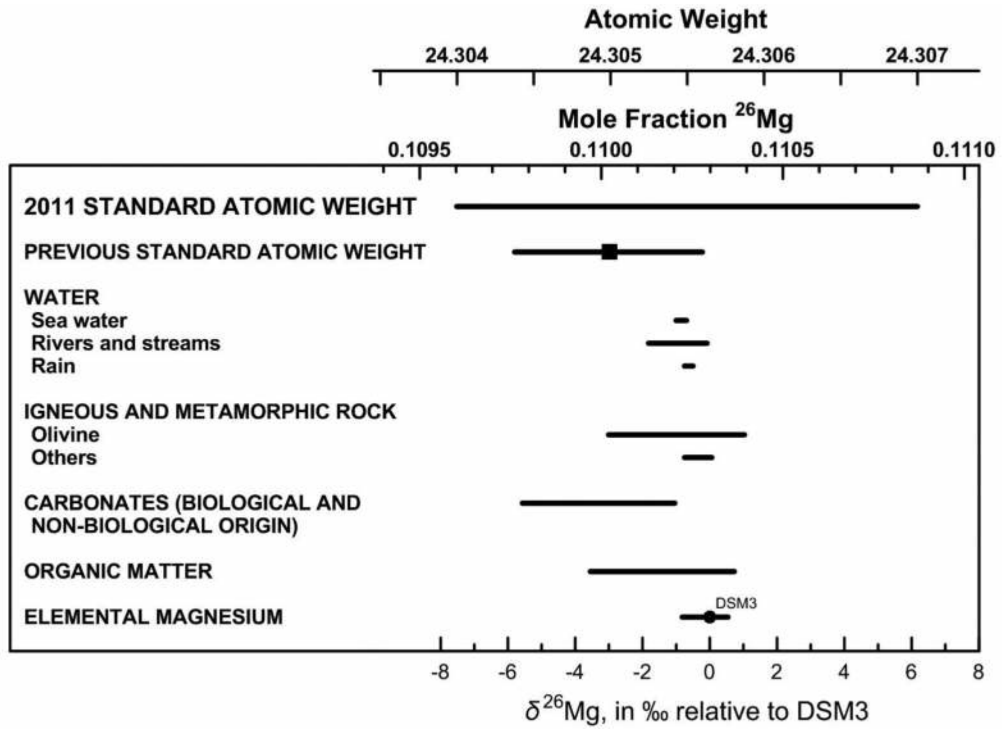

Fig. 3 Variation in isotopic composition and atomic weight of magnesium in selected magnesium-bearing materials. The δ^{26}Mg measurements are expressed relative to DSM3 because many materials were measured relative to it. However, DSM3 is not recommended as the international measurement standard for the δ^{26}Mg scale. Data for water are from [36–38]. Data for carbonates are from [32]. Data for igneous and metamorphic rocks are from [33,34]. Data for organic matter are from [37,38]. Data for elemental magnesium are from [35]. Isotopic reference material is designated by solid black circles. The isotopic reference material SRM 980 elemental magnesium is not shown because it is isotopically inhomogeneous [31]. The previous (1985 to 2009) standard atomic weight of magnesium was 24.3050(6). The atomic-weight uncertainty of the best measurement of isotopic abundance [31] is approximately ±0.000 24, which is about 40 % that of the uncertainty of the 2009 standard atomic weight [8] and 12 times smaller than the 2011 standard-atomic-weight interval. The δ^{26}Mg scale and the ^{26}Mg mole-fraction scale were matched using data from [31], and the uncertainty in placement of the atomic-weight scale and the ^{26}Mg mole-fraction scale relative to the δ^{26}Mg scale is equivalent to 1.1 ‰.

3.5 Mercury

The Commission has changed the recommended value for the standard atomic weight of mercury, A_r(Hg), from 200.59(2) to 200.592(3) based on new measurements and an evaluation of the effect of the variation in isotopic abundance in normal materials by Meija and co-workers [41]. Measurements were made using a multicollector inductively coupled plasma-mass spectrometer using NIST SRM997 thallium isotopic reference material for mass-bias correction, and the investigation followed an approach similar to that used in the determination of the atomic weight of indium. The authors accounted for the difference in mass bias between thallium and mercury. The uncertainty of this new recommended value for the standard atomic weight includes the uncertainty of the standard atomic weight of thallium reported by IUPAC. Although variations in the isotopic composition of mercury have been demonstrated, those variations are too small to affect the determination of the standard atomic weight significantly. The previous standard atomic-weight value, A_r(Hg) = 200.59(2), recommended in 1989, was based on a determination of a nonreference material by Zadnik et al. [42]. Historical values for A_r(Hg) include [22]: 1882, 200.17; 1894, 200.0; 1912, 200.6; 1925, 200.61; 1961, 200.59; 1969, 200.59(3); 1989, 200.59(2).

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

Half-lives and relative atomic mass values have been compiled for selected radioactive isotopes and are summarized in Table 3. Long-lived radioactive isotopes of elements with a characteristic terrestrial isotopic composition that contribute to the standard atomic weight determinations are marked with the symbol (†) in the table. Selected radioactive isotopes for elements with no stable isotopes, with no characteristic terrestrial isotopic composition and with no standard atomic weight are presented without this symbol.

Table 3 Relative atomic masses and half-lives of selected radioactive nuclides.

a = year; d = day; h = hour; min = minute; s = second; ms = millisecond; † indicates isotope contributing to the determination of a standard atomic weight.

Atomic number	Element name	Symbol	Mass number	Atomic mass/u	Half-life	Unit
19	potassium	K	$40^{\dagger}$	39.96400	$1.248(3) \times 10^{9}$	a
20	calcium	Ca	$48^{\dagger}$	47.9525	$4.4(6) \times 10^{19}$	a
23	vanadium	V	$50^{\dagger}$	49.94716	$1.4(4) \times 10^{17}$	a
32	germanium	Ge	$76^{\dagger}$	75.9214	$1.5(1) \times 10^{21}$	a
34	selenium	Se	$82^{\dagger}$	81.9167	$0.92(7) \times 10^{20}$	a
37	rubidium	Rb	$87^{\dagger}$	86.909180	$4.97(1) \times 10^{10}$	a
40	zirconium	Zr	$96^{\dagger}$	95.9083	$2.3(2) \times 10^{19}$	a
42	molybdenum	Mo	$100^{\dagger}$	99.9075	$7(1) \times 10^{18}$	a
43	technetium	Tc	97	96.9064	$4.2(16) \times 10^{6}$	a
			98	97.9072	$6.1(10) \times 10^{5}$	a
			99	98.9063	$2.1(3) \times 10^{5}$	a
48	cadmium	Cd	$113^{\dagger}$	112.9044	$8.04(5) \times 10^{15}$	a
			$116^{\dagger}$	115.9048	$3.0(2) \times 10^{19}$	a
49	indium	In	$115^{\dagger}$	114.9039	$4.4(3) \times 10^{14}$	a
52	tellurium	Te	$128^{\dagger}$	127.9045	$2.5(3) \times 10^{24}$	a
			$130^{\dagger}$	129.9062	$7(1) \times 10^{20}$	a
54	xenon	Xe	$136^{\dagger}$	135.9072	$2.3(2) \times 10^{21}$	a
56	barium	Ba	$130^{\dagger}$	129.9063	$2.2(5) \times 10^{21}$	a
57	lanthanum	La	$138^{\dagger}$	137.9071	$1.06(4) \times 10^{11}$	a
60	neodymium	Nd	$144^{\dagger}$	143.9101	$2.3(2) \times 10^{15}$	a
			$150^{\dagger}$	149.9209	$1.33(5) \times 10^{20}$	a
61	promethium	Pm	145	144.9127	17.7(4)	a
			146	145.9147	5.53(5)	a
			147	146.9151	2.623(3)	a
62	samarium	Sm	$147^{\dagger}$	146.9149	$1.07(1) \times 10^{11}$	a
			$148^{\dagger}$	147.9148	$7(3) \times 10^{15}$	a
71	lutetium	Lu	$176^{\dagger}$	175.9427	$3.73(3) \times 10^{10}$	a
72	hafnium	Hf	$174^{\dagger}$	173.94	$2.0(4) \times 10^{15}$	a
74	tungsten	W	$180^{\dagger}$	179.9467	$1.8(2) \times 10^{18}$	a
75	rhenium	Re	$187^{\dagger}$	186.95575	$4.16(1) \times 10^{10}$	a
76	osmium	Os	$186^{\dagger}$	185.95384	$2(1) \times 10^{15}$	a
78	platinum	Pt	$190^{\dagger}$	189.9599	$4.5(1) \times 10^{11}$	a

(*continues on next page*)

Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
83	bismuth	Bi	209†	208.9804	$2.0(1) \times 10^{19}$	a
84	polonium	Po	208	207.9812	2.90(1)	a
			209	208.9824	$1.28(7) \times 10^{2}$	a
			210	209.9829	138.4(1)	d
85	astatine	At	210	209.9871	8.1(4)	h
			211	210.9875	7.21(1)	h
86	radon	Rn	210	209.9897	2.4(1)	h
			211	210.9906	14.6(2)	h
			222	222.0176	3.823(4)	d
87	francium	Fr	212	211.9962	20.0(6)	min
			222	222.0176	14.2(3)	min
			223	223.0197	22.0(1)	min
88	radium	Ra	226	226.0254	$1.599(4) \times 10^{3}$	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	$7.56(3) \times 10^{4}$	a
			232†	232.0381	$1.40(1) \times 10^{10}$	a
91	protactinium	Pa	231†	231.0359	$3.25(1) \times 10^{4}$	a
			233	233.04025	27.0(1)	d
92	uranium	U	233	233.0396	$1.590(3) \times 10^{5}$	a
			234†	234.041	$2.454(2) \times 10^{5}$	a
			235†	235.0439	$7.034(2) \times 10^{8}$	a
			236	236.0456	$2.342(4) \times 10^{7}$	a
			238†	238.0508	$4.468(5) \times 10^{9}$	a
93	neptunium	Np	236	236.0466	$1.55(6) \times 10^{5}$	a
			237	237.0482	$2.14(1) \times 10^{6}$	a
94	plutonium	Pu	238	238.0496	87.7(1)	a
			239	239.0522	$2.410(3) \times 10^{4}$	a
			240	240.0538	$6.56(1) \times 10^{3}$	a
			241	241.0569	14.33(3)	a
			242	242.0587	$3.75(2) \times 10^{5}$	a
			244	244.0642	$8.12(3) \times 10^{7}$	a
95	americium	Am	241	241.0568	432.7(6)	a
			243	243.0614	$7.37(2) \times 10^{3}$	a
96	curium	Cm	243	243.0614	29.1(1)	a
			244	244.0628	18.3(1)	a
			245	245.0655	$8.48(6) \times 10^{3}$	a
			246	246.0672	$4.73(3) \times 10^{3}$	a
			247	247.0704	$1.56(5) \times 10^{7}$	a
			248	248.0723	$3.48(6) \times 10^{5}$	a
97	berkelium	Bk	247	247.0703	$1.4(3) \times 10^{3}$	a
			249	249.075	$3.20(3) \times 10^{2}$	d
98	californium	Cf	249	249.0749	351(2)	a
			250	250.0764	13.1(1)	a
			251	251.0796	$9.0(5) \times 10^{2}$	a
			252	252.0816	2.65(1)	a

(*continues on next page*)

Table 3 (*Continued*).

Atomic number	Element name	Symbol	Mass number	Atomic mass	Half-life	Unit
99	einsteinium	Es	252	252.083	472(2)	d
			254	254.088	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	260.1	27.8(3)	d
102	nobelium	No	255	255.0932	3.1(2)	min
			259	259.101	58(5)	min
103	lawrencium	Lr	251	251.09	~39	min
			261	261.11	~40	min
			262	262.11	3.6(3)	h
104	rutherfordium	Rf	265	265.12	~11	min
			267	267.12	~1	h
105	dubnium	Db	268	268.13	26(6)	h
			270	270.13	~0.9	d
106	seaborgium	Sg	267	267.12	~1.3	min
			271	271.13	~2	min
107	bohrium	Bh	270	270.13	~1	min
			274	274.14	~0.9	min
108	hassium	Hs	270	270.13	23	s
			277	277.15	~0.8	min
109	meitnerium	Mt	276	276.15	~6	s
			278	278.16	~5	s
110	darmstadtium	Ds	280	280.16	~7.6	s
			281	281.17	20(8)	s
111	roentgenium	Rg	281	281.17	22(8)	s
			282	282.17	~0.7	min
112	copernicium	Cn	283	283.17	4(1)	s
			285	285.18	0.8	min
113	ununtritium	Uut	285	285.18	6(2)	s
			286	286.18	~0.9	s
114	flerovium	Fl	288	288.19	0.8(2)	s
			289	289.19	3(1)	s
115	ununpentium	Uup	288	288.19	0.17(4)	s
			289	289.19	0.4(2)	s
			290	290.2	~0.2	s
116	livermorium	Lv	291	291.2	~0.02	s
			292	292.2	0.02(1)	s
			293	293.2	0.08(7)	s
117	ununseptium	Uus	293	293.21	0.03(1)	s
			294	294.21	~0.05	s
118	ununoctium	Uuo	294	294.21	0.7(6)	ms

Names of elements with atomic number 113, 115, 117, and 118 are provisional; they have been reported in the peer-reviewed scientific literature, but they have not yet been named by IUPAC. Listing of particular isotopes for these elements does not imply any priority of the discovery of those elements on the part of IUPAC or the Commission on Isotopic Abundances and Atomic Weights. There is no general agreement on which of the various 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.

The Commission has no official responsibility for the dissemination of atomic masses or radioactive half-lives. The information contained in this table will enable the user to calculate atomic weights of radioactive materials with a variety of isotopic compositions. The atomic mass values listed are considered to be accurate to ±1 in the last digit quoted and are taken from the 2012 atomic mass table [43]. The half-life values quoted can be considered accurate at the one standard deviation level and are taken from the "Table of the Isotopes" of the *CRC Handbook of Chemistry and Physics* and its updates [44].

5. ABRIDGED TABLES OF STANDARD ATOMIC WEIGHTS

The detail and number of significant digits reported in the full Table of Standard Atomic Weights (Tables 1 and 2) exceeds the needs and the interests of many users. Tables abridged to four or five significant digits are published with the expectation that subsequent changes to the abridged values will be minimal. Standard atomic weights abridged to four and five significant digits are presented in Tables 4 and 5, respectively. Users seeking an atomic-weight value that is not an interval, such as for trade and commerce, can refer to a conventional atomic-weight value in Section 6.

Table 4 Standard atomic weights 2011 abridged to four significant digits. [Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights of many elements are not invariant, but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant digit to which they are attributed) apply to elements from normal materials. 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 12 of these elements, the standard atomic weight is given as an atomic-weight interval with the symbol $[a, b]$ to denote the set of atomic-weight values in normal materials; thus, $a \le A_r(E) \le b$. The symbols a and b denote the lower and upper bounds of the interval $[a, b]$, respectively. Names of elements with atomic number 113, 115, 117, and 118 are provisional; they have been reported in the peer-reviewed, scientific literature, but they have not yet been named by IUPAC.

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	[24.30, 24.31]
13	aluminium (aluminum)	Al	26.98
14	silicon	Si	[28.08, 28.09]

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Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
15	phosphorus	P	30.97
16	sulfur	S	[32.05, 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, 79.91]
36	krypton	Kr	83.80#
37	rubidium	Rb	85.47#
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#

(*continues on next page*)

Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
64	gadolinium	Gd	157.3#
65	terbium	Tb	158.9
66	dysprosium	Dy	162.5#
67	holmium	Ho	164.9
68	erbium	Er	167.3#
69	thulium	Tm	168.9
70	ytterbium	Yb	173.1#
71	lutetium	Lu	175.0
72	hafnium	Hf	178.5
73	tantalum	Ta	180.9
74	tungsten	W	183.8
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	
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	

(*continues on next page*)

Table 4 (*Continued*).

Atomic number	Element name	Symbol	Atomic weight
113	ununtrium*	Uut	
114	flerovium	Fl	
115	ununpentium*	Uup	
116	livermorium*	Lv	
117	ununseptium*	Uus	
118	ununoctium*	Uuo	

*Element has no stable isotopes. One or more representative isotopes are given in Table 3 with the appropriate relative atomic mass and half-life. However, four such elements (Bi, Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these elements, standard atomic weights are tabulated.

#Values may differ from the atomic weights of the relevant elements in some normal materials because of a variation in the isotopic abundances of the element's stable isotopes.

Table 5 Standard atomic weights 2011 abridged to five significant digits.
[Scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.]

The atomic weights of many elements are not invariant, but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant digit to which they are attributed) apply to elements from normal materials. 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 12 of these elements, the standard atomic weight is given as an atomic-weight interval with the symbol [*a*, *b*] to denote the set of atomic-weight values in normal materials; thus, $a \le A_r(E) \le b$. The symbols *a* and *b* denote the lower and upper bounds of the interval [*a*, *b*], respectively. Names of elements with atomic number 113, 115, 117, and 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	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	[24.304, 24.307]	
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

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Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
18	argon	Ar	39.948	g r
19	potassium	K	39.098	g
20	calcium	Ca	40.078(4)	g
21	scandium	Sc	44.956	
22	titanium	Ti	47.867	
23	vanadium	V	50.942	
24	chromium	Cr	51.996	
25	manganese	Mn	54.938	
26	iron	Fe	55.845(2)	
27	cobalt	Co	58.933	
28	nickel	Ni	58.693	r
29	copper	Cu	63.546(3)	r
30	zinc	Zn	65.38(2)	r
31	gallium	Ga	69.723	
32	germanium	Ge	72.630	
33	arsenic	As	74.922	
34	selenium	Se	78.96(3)	r
35	bromine	Br	[79.901, 79.907]	
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	

(*continues on next page*)

Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
66	dysprosium	Dy	162.50	g
67	holmium	Ho	164.93	
68	erbium	Er	167.26	g
69	thulium	Tm	168.93	
70	ytterbium	Yb	173.05	g
71	lutetium	Lu	174.97	g
72	hafnium	Hf	178.49(2)	
73	tantalum	Ta	180.95	
74	tungsten	W	183.84	
75	rhenium	Re	186.21	
76	osmium	Os	190.23(3)	g
77	iridium	Ir	192.22	
78	platinum	Pt	195.08	
79	gold	Au	196.97	
80	mercury	Hg	200.59	
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		

(*continues on next page*)

Table 5 (*Continued*).

Order of atomic number				
Atomic number	Element name	Symbol	Atomic weight	Footnotes
114	flerovium*	Fl		
115	ununpentium*	Uup		
116	livermorium*	Lv		
117	ununseptium*	Uus		
118	ununoctium*	Uuo		

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

g Geological materials 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 materials 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 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

The Commission recognizes that some users of atomic-weight data only need representative values. Therefore, for those elements with standard atomic weights given as intervals, the Commission provides conventional atomic-weight values (Table 6). These conventional quantity values have no uncertainty values associated with them. They have been selected so that most or all atomic-weight variation in normal materials is covered in an interval of plus or minus one in the last digit.

Table 6 Conventional atomic weights 2011.

[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
bromine	Br	35	79.904
carbon	C	6	12.011
chlorine	Cl	17	35.45
hydrogen	H	1	1.008
lithium	Li	3	6.94
magnesium	Mg	12	24.305
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. PERIODIC TABLE OF THE ISOTOPES

The Periodic Table of the Elements, developed independently by Mendeleev and Meyer in the late 19th century, represents a remarkable achievement in our understanding of the structure of the atoms and the chemical and physical properties of the elements. Traditionally, the Periodic Table includes the standard atomic weights of the elements. With the introduction of intervals to represent the standard atomic weights for elements that have large variations in isotopic abundance from which atomic weights are calculated, members of the Commission together with assistance from the IUPAC Committee on Chemistry Education proposed to develop a periodic table of the isotopes for the educational community [45]. The goal of this IUPAC-sponsored project is to produce learner-oriented materials on an interactive periodic table to emphasize the existence of isotopes, the role of isotopic abundances in the determination of atomic weights, and applications in science and industry.

The IUPAC Periodic Table of the Isotopes produced by members of the task group, shown in Fig. 4, employs colored tiles to distinguish among four categories of the elements: (a) element with two or more isotopes that are used to determine the standard atomic weight, which varies in normal materials and is represented with an interval; (b) element with two or more isotopes with variable isotopic abundances that are used to determine the standard atomic weight, but the upper and lower bounds of the standard atomic weight have not been assigned by IUPAC or the variations may be too small to affect the atomic-weight value; (c) element with only one isotope that is used to determine the standard atomic weight; and (d) element with no standard atomic weight because all of its isotopes are radioactive and no isotope occurs with a characteristic terrestrial isotopic composition in normal materials.

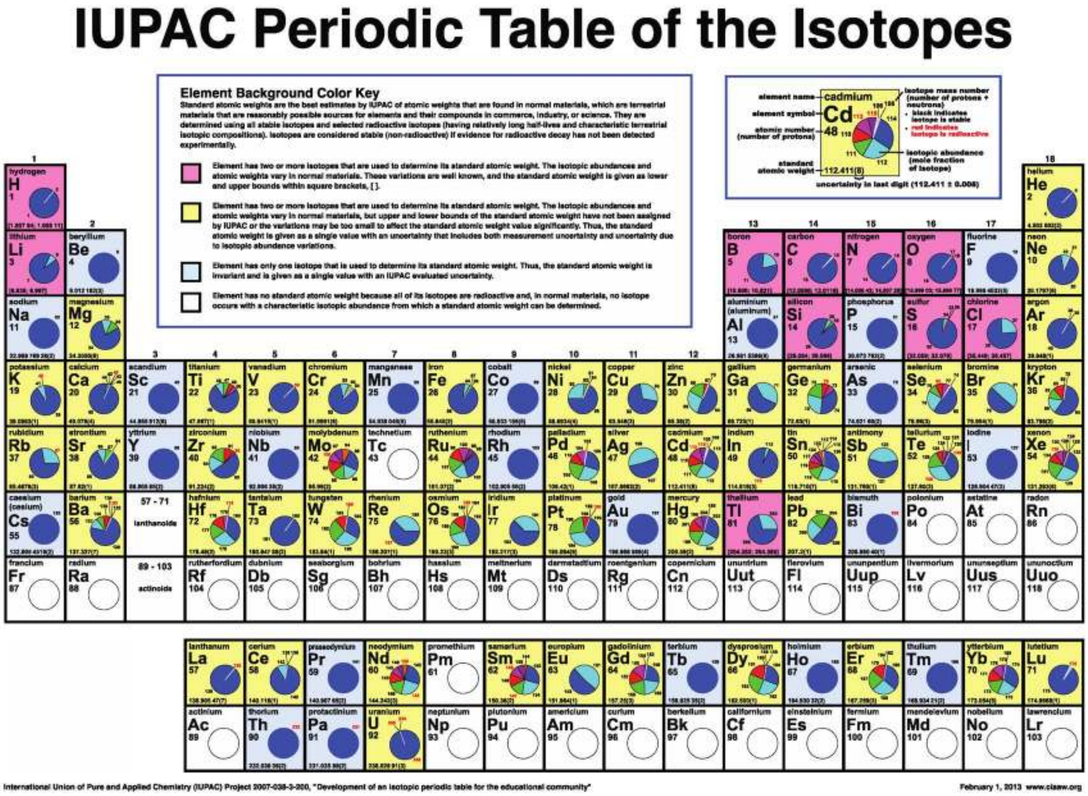

Fig. 4 IUPAC Periodic Table of the Isotopes. This is a revised and updated version [46] of the figure originally presented in ref. [47].

In addition, pie diagrams provide an overview of the relative abundances of the isotopes that were used in the determination of standard-atomic-weight values.

8. MEMBERSHIP OF SPONSORING BODIES

Membership of the Inorganic Chemistry Division Committee for the period 2010–2011 was as follows:

President: R. D. Loss (Australia); ***Past President***: K. Tatsumi (Japan); ***Secretary***: L. V. Interrante (USA); ***Vice President***: J. Reedijk (Netherlands); ***Titular Members***: T. Ding (China); N. E. Holden (USA); P. Karen (Norway); J. Garcia-Martinez (Spain); S. Mathur (Germany); K. Sakai (Japan); ***Associate Members***: T. V. Basova (Russia); M. Drábik (Slovakia); M. Leskela (Finland); L. K. Liu (China/Taipei); L. R. Öhrström (Sweden); T. B. Coplen (USA); ***National Representatives***: T. Hossain Tarafder (Bangladesh); N. Trendafilova (Bulgaria); Chandrasekhar (India); R. Gonfiantini (Italy); T. Dasgupta (Jamaica); K. Yoon (Korea); L. Y. Goh (Malaysia); A. Kilic (Turkey); A. West (UK); A. Bologna Alles (Uruguay).

Membership of the Commission on Isotopic Abundances and Atomic Weights for the period 2010–2011 was as follows:

Chair: W. A. Brand (Germany); ***Secretary***: M. Wieser (Canada); ***Titular Members***: M. Berglund (Belgium); M. Gröning (Austria); T. Hirata (Japan); R. Schoenberg (Germany); T. Walczyk (Singapore); S. Yoneda (Japan); ***Associate Members***: J. Meija (Canada); T. Prohaska (Austria); T. Walczyk (Singapore); X. K. Zhu (China); P. Vallelonga (Australia); ***National Representatives***: J. K. Böhlke (USA); P. De Bièvre (Belgium); S. Yoneda (Japan).

The Commission on Isotopic Abundances and Atomic Weights notes the death of a former member and secretary of the Commission. Prof. J. R. de Laeter, 1933–2010, was an expert in both radioactive and stable isotopes, and the measurement and evaluation of atomic weights. A long-time active contributor to IUPAC, John held various positions as an Associate Member, Titular Member, National Representative, Secretary of the Commission, and Chair of the Commission, and other subcommittees over the period 1980–2010. One of John's significant achievements was leading a major overview of the atomic weights of the elements during the 20th century, published in 2003 [10,11].

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