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Atomic weights of the elements 2013 (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 19 elements. The standard atomic weights of four elements have been revised based on recent determinations of isotopic abundances in natural terrestrial materials:

cadmium to 112.414(4) from 112.411(8),
molybdenum to 95.95(1) from 95.96(2),
selenium to 78.971(8) from 78.96(3), and
thorium to 232.0377(4) from 232.038 06(2).

The Commission on Isotopic Abundances and Atomic Weights (ciaaw.org) also revised the standard atomic weights of fifteen elements based on the 2012 Atomic Mass Evaluation:

aluminium (aluminum) to 26.981 5385(7) from 26.981 5386(8),
arsenic to 74.921 595(6) from 74.921 60(2),
beryllium to 9.012 1831(5) from 9.012 182(3),
caesium (cesium) to 132.905 451 96(6) from 132.905 4519(2),
cobalt to 58.933 194(4) from 58.933 195(5),
fluorine to 18.998 403 163(6) from 18.998 4032(5),
gold to 196.966 569(5) from 196.966 569(4),
holmium to 164.930 33(2) from 164.930 32(2),
manganese to 54.938 044(3) from 54.938 045(5),
niobium to 92.906 37(2) from 92.906 38(2),
phosphorus to 30.973 761 998(5) from 30.973 762(2),
praseodymium to 140.907 66(2) from 140.907 65(2),

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scandium to 44.955 908(5) from 44.955 912(6),
thulium to 168.934 22(2) from 168.934 21(2), and
yttrium to 88.905 84(2) from 88.905 85(2).

The Commission also recommends the standard value for the natural terrestrial uranium isotope ratio, $N(^{238}U)/N(^{235}U) = 137.8(1)$.

Keywords: atomic weights; atomic-weight intervals; cadmium; ciaaw.org; conventional atomic-weight values; half-life; IUPAC Technical Report; molybdenum; selenium; standard atomic weight; standardization; thorium; uranium.

Dedicated to Norman Neill Greenwood – the 7th Chairman of the Commission.

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 German Chemical Society 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]. In 1979 [2], 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 terrestrial sources."

In recent times, the Table of Standard Atomic Weights has been published biennially, and their values are virtually unchallenged throughout the world. The detail and number of significant digits reported in the full Table of Standard Atomic Weights exceeds the needs and the interests of many users. A Table abridged to five significant digits is published with the expectation that subsequent changes to the abridged values will be minimal.

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 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 amount fractions of their isotopes in normal materials [3], including some chemical reagents [4]. 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." [5, 6]

Thus, the standard atomic-weight values published by the Commission are intended to encompass all naturally occurring materials with the highest possible reliability, such that standard atomic-weight values are rarely corrected. 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 [7]. 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 Joint Committee for Guides in Metrology (JCGM) [8], and they are consistent with those calculated from the isotopic abundances listed in Column 9 of the Table of Isotopic Composition of the Elements [9]. Beginning with the 2009 Table of Standard Atomic Weights [10], 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 [5, 6, 11, 12].

The Commission met in Gebze, Turkey, under the chairmanship of Dr. Willi A. Brand from 7 to 8 August 2013, prior to the 47th IUPAC General Assembly in Istanbul. At this meeting, the Commission reviewed recommendations of its Subcommittee on Isotopic Abundance Measurements (SIAM), which suggested changes in the standard atomic weights of some elements based on its review of published data.

1.1 Atomic weight of an element

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

$$A_r(^{i}E)_P = \frac{m_a(^{i}E)_P}{m_a(^{12}C)/12} = \frac{m_a(^{i}E)_P}{Da} \quad (1)$$

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

$$A_r(E)_P = \sum [x(^{i}E)_P \times A_r(^{i}E)] \quad (2)$$

where $x(^{i}E)_P$ is the amount fraction of isotope ^{i}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, $A_r(E)$,

of element E in a material can be determined from knowledge of the atomic masses of the isotopes of that element and the corresponding amount 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 252, and (2) selected radioactive isotopes that have relatively long half-lives and characteristic terrestrial isotopic compositions, of which there are 37. A radioactive isotope of an element is said to have a *characteristic terrestrial isotopic composition* [13] if it contributes significantly and reproducibly to the determination of the standard atomic weight of the element in normal materials.

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, $U[A_r(\mathrm{E})]$, 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 Subcommittees and through subsequent IUPAC projects.

All known elements can be categorized according to the following constraints on their standard atomic weights (see Section 9 for details):

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. These elements have a white background for each element cell on the IUPAC Periodic Table of the Isotopes [14].

2. Elements whose standard atomic weight is determined by only one stable isotope, *e.g.* sodium. The standard atomic weight is derived from the atomic mass of its stable isotope [15–17]. These elements have a blue background for each element cell on the IUPAC Periodic Table of the Isotopes [14].
3. Elements whose standard atomic weight is determined by more than one isotope are shown on the IUPAC Periodic Table of the Isotopes with a yellow background [14]. They are subdivided into three groups:
   a. Elements have 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. Elements in this subcategory may enter category 3b as more accurate isotopic-abundance measurements are published.
   b. Elements have 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. Elements in this subcategory can advance to category 3c as best-measurement results improve.
   c. Elements have 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). Elements in this subcategory can advance to category 4 as the Commission completes evaluations and assigns intervals. The Commission uses the footnote "r" to identify elements in this subcategory for which the standard-atomic-weight uncertainty has been expanded to account for known atomic-weight variability.
4. Elements with two or more isotopes having known variations in atomic weights 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.* hydrogen (Fig. 1). These elements have a pink background for each element cell on the IUPAC Periodic Table of the Isotopes [14].

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 categories 3 and 4, 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, whereas the uncertainty of the atomic weight calculated from the best measurement of the isotopic abundance of carbon is approximately thirty times smaller [9, 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 $a \le x \le b$, 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 [20–22] is the basis for the determination of the atomic-weight bound [23]. The isotope delta is obtained from isotope-number ratio $R(^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{P}}$

$$R({}^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{P}} = \frac{N({}^{i}\mathrm{E})_{\mathrm{P}}}{N({}^{j}\mathrm{E})_{\mathrm{P}}} \tag{3}$$

where $N(^{i}\mathrm{E})_{\mathrm{P}}$ and $N(^{j}\mathrm{E})_{\mathrm{P}}$ are the numbers of each isotope, and $^{i}\mathrm{E}$ denotes the higher (superscript *i*) and $^{j}\mathrm{E}$ the lower (superscript *j*) atomic mass number of chemical element E in substance P. The isotope-delta value (symbol δ), also called the relative isotope-ratio difference, is a differential measurement obtained from isotope-number ratios of substance P and a reference material Ref.

$$\delta({}^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{P,Ref}} = \frac{R({}^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{P}} - R({}^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{Ref}}}{R({}^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{Ref}}} \tag{4}$$

A more convenient short-hand notation for isotope-delta value is typically found in scientific publications; $\delta(^{i}\mathrm{E}, {}^{j}\mathrm{E})_{\mathrm{P,Ref}}$ is shortened to $\delta^{i}\mathrm{E}_{\mathrm{Ref}}$ or to $\delta^{i}\mathrm{E}$. For example, $\delta(^{13}\mathrm{C}, {}^{12}\mathrm{C})_{\mathrm{P,VPDB}}$ is shortened to either $\delta^{13}\mathrm{C}_{\mathrm{VPDB}}$ or $\delta^{13}\mathrm{C}$ [20, 22], where VPDB is the Vienna Peedee belemnite–LSVEC scale for carbon isotope-delta measurements [22].

Isotope-delta values are small numbers and therefore frequently presented in multiples of 10^{-3} or per mil (symbol ‰). To match an isotope-delta scale of an element to an isotope-amount scale (both shown in Figs. 1–12), a substance is needed whose carbon isotopic abundances and whose isotope-delta value is also well known relative to the isotope-delta scale. Commonly this substance is an isotopic reference material that has served as the "best measurement" for determination of isotopic abundance [9]. For example, consider carbon shown in Fig. 4. The $x(^{13}\mathrm{C})$ scale is matched to the $\delta^{13}\mathrm{C}_{\mathrm{VPDB}}$ scale through measurement of the isotopic reference material NBS 19 calcium carbonate, which has been assigned the consensus $\delta^{13}\mathrm{C}_{\mathrm{VPDB}}$ value of +1.95 ‰ [41]. The carbon isotope number ratio, $R(^{13}\mathrm{C}, {}^{12}\mathrm{C})$, of NBS 19 has been measured by Chang and Li [18] and is 0.011 202(28), and this measurement serves as the "best measurement" of a single terrestrial source [9]. VPDB is the zero point on the carbon isotope-delta scale and therefore $\delta^{13}\mathrm{C}_{\mathrm{VPDB}} = 0$. Hence,

$$R({}^{13}\mathrm{C}, {}^{12}\mathrm{C})_{\mathrm{VPDB}} = 0.011\,202/(1 + 1.95 \times 0.001) = 0.011\,180 \tag{5}$$

because ‰ = 0.001. Therefore, ignoring the uncertainty (discussed below), the relation between carbon isotope-delta values and $^{13}\mathrm{C}$ amount fractions is

$$x({}^{13}\mathrm{C})_{\mathrm{P}} = \frac{1}{1 + \dfrac{1}{R({}^{13}\mathrm{C}, {}^{12}\mathrm{C})_{\mathrm{VPDB}} \cdot (1 + \delta^{13}\mathrm{C}_{\mathrm{P,VPDB}})}} \tag{6}$$

For example, consider the material with the lowest measured $^{13}\mathrm{C}$ abundance (Fig. 4), which is crocetane (2,6,11,15-tetramethylhexadecane), produced at cold seeps of the eastern Aleutian subduction zone, having a published $\delta^{13}\mathrm{C}_{\mathrm{VPDB}}$ value of –(130.3 ± 0.3) ‰ [42]. The $x(^{13}\mathrm{C})$ value of this specimen is found using equation (6) and is 0.009 630(3). The atomic weight of this specimen is calculated from equation (2) using the $^{12}\mathrm{C}$ and $^{13}\mathrm{C}$ isotopic abundances in the specimen (1 – 0.009 630(3) and 0.009 630(3), respectively), and the atomic-

weight values of ^{12}C and ^{13}C isotopes, which are 12 and 13.003 354 835(2) [16], respectively. For this material, $A_r(C) = 12.009\ 662(3)$.

If material P is the normal material having the lowest atomic weight of element E, then

$$\text{lower bound} = \text{lowest } A_r(E)_P - U[A_r(E)]_P \quad (7)$$

where $U[A_r(E)]_P$ 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 isotope-amount fraction and atomic-weight scales. The latter is the uncertainty in relating an isotope-delta scale to an atomic-weight scale.

2 The table of standard atomic weights

The Table of Standard Atomic Weights 2013 is given in the order of atomic number (Table 1) and it replaces the Table of Standard Atomic Weights 2011 [43]. 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 nor 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 2013 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). For each of these elements, a graphical plot of natural variations of isotopic abundances and atomic weights is provided in this report, and figure numbers are provided in Table 1 for the interested reader.[1]

For elements within categories 2 to 5 (see section 1.4 for category descriptions), a decisional uncertainty, $U[A_r(E)]$, is given in parentheses following the last significant figure to which it is attributed. The interval $A_r(E) - U[A_r(E)]$ to $A_r(E) + U[A_r(E)]$ may be expected to encompass atomic-weight values of normal materials.

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 Coplen and Peiser [44] and subsequent Commission publications.

3 Comments on atomic weights of selected elements

Since the inaugural International Atomic Weights report, published in 1903, the Commission has provided a rationale for the changes in the recommended atomic weights. This description is accompanied by the list of recommended values since 1903. Brief descriptions of the changes to the standard atomic weights resulting from the Commission meeting in 2013 are provided below.

3.1 Cadmium

The Commission has changed the recommended value for the standard atomic weight of cadmium, $A_r(Cd)$, to 112.414(4) from 112.411(8) based on an evaluation published by Pritzkow *et al.* [45]. While the majority of atomic-weight determinations of multi-isotopic elements employ a single gravimetrically prepared mixture of two near-pure isotopes, this work is a *tour de force* of seven near-pure isotopes of cadmium (cadmium has a total of eight stable isotopes). Such an approach, albeit resource-intensive, allows the calibration of

1 Editor Note: The uncertainties associated with these values are not well-understood which is why in 2013 IUPAC launched Project 2013-032-1-200. The upcoming Recommendation of this Project will provide guidance on the use of standard atomic weights and their uncertainties.

Table 1: Standard atomic weights 2013. Atomic weights are 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. 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. The footnotes to this table elaborate the types of variation that may occur for individual elements and that may lie outside the values listed. Names and symbols 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 officially named.

Element name	Symbol	Atomic number	Standard atomic weight	See also figure	Footnotes
hydrogen	H	1	[1.007 84, 1.008 11]	1	m
helium	He	2	4.002 602(2)		g r
lithium	Li	3	[6.938, 6.997]	2	m
beryllium	Be	4	9.012 1831(5)		
boron	B	5	[10.806, 10.821]	3	m
carbon	C	6	[12.0096, 12.0116]	4	
nitrogen	N	7	[14.006 43, 14.007 28]	5	m
oxygen	O	8	[15.999 03, 15.999 77]	6	m
fluorine	F	9	18.998 403 163(6)		
neon	Ne	10	20.1797(6)		g m
sodium	Na	11	22.989 769 28(2)		
magnesium	Mg	12	[24.304, 24.307]	7	
aluminium (aluminum)	Al	13	26.981 5385(7)		
silicon	Si	14	[28.084, 28.086]	8	
phosphorus	P	15	30.973 761 998(5)		
sulfur	S	16	[32.059, 32.076]	9	
chlorine	Cl	17	[35.446, 35.457]	10	m
argon	Ar	18	39.948(1)		g r
potassium	K	19	39.0983(1)		
calcium	Ca	20	40.078(4)		g
scandium	Sc	21	44.955 908(5)		
titanium	Ti	22	47.867(1)		
vanadium	V	23	50.9415(1)		
chromium	Cr	24	51.9961(6)		
manganese	Mn	25	54.938 044(3)		
iron	Fe	26	55.845(2)		
cobalt	Co	27	58.933 194(4)		
nickel	Ni	28	58.6934(4)		r
copper	Cu	29	63.546(3)		r
zinc	Zn	30	65.38(2)		r
gallium	Ga	31	69.723(1)		
germanium	Ge	32	72.630(8)		
arsenic	As	33	74.921 595(6)		
selenium	Se	34	78.971(8)		r
bromine	Br	35	[79.901, 79.907]	11	
krypton	Kr	36	83.798(2)		g m
rubidium	Rb	37	85.4678(3)		g
strontium	Sr	38	87.62(1)		g r
yttrium	Y	39	88.905 84(2)		
zirconium	Zr	40	91.224(2)		g
niobium	Nb	41	92.906 37(2)		
molybdenum	Mo	42	95.95(1)		g
technetium*	Tc	43	–		
ruthenium	Ru	44	101.07(2)		g
rhodium	Rh	45	102.905 50(2)		
palladium	Pd	46	106.42(1)		g
silver	Ag	47	107.8682(2)		g
cadmium	Cd	48	112.414(4)		g

Table 1 (continued)

Element name	Symbol	Atomic number	Standard atomic weight	See also figure	Footnotes
indium	In	49	114.818(1)		
tin	Sn	50	118.710(7)		g
antimony	Sb	51	121.760(1)		g
tellurium	Te	52	127.60(3)		g
iodine	I	53	126.904 47(3)		
xenon	Xe	54	131.293(6)		g m
caesium (cesium)	Cs	55	132.905 451 96(6)		
barium	Ba	56	137.327(7)		
lanthanum	La	57	138.905 47(7)		g
cerium	Ce	58	140.116(1)		g
praseodymium	Pr	59	140.907 66(2)		
neodymium	Nd	60	144.242(3)		g
promethium*	Pm	61	–		
samarium	Sm	62	150.36(2)		g
europium	Eu	63	151.964(1)		g
gadolinium	Gd	64	157.25(3)		g
terbium	Tb	65	158.925 35(2)		
dysprosium	Dy	66	162.500(1)		g
holmium	Ho	67	164.930 33(2)		
erbium	Er	68	167.259(3)		g
thulium	Tm	69	168.934 22(2)		
ytterbium	Yb	70	173.054(5)		g
lutetium	Lu	71	174.9668(1)		g
hafnium	Hf	72	178.49(2)		
tantalum	Ta	73	180.947 88(2)		
tungsten	W	74	183.84(1)		
rhenium	Re	75	186.207(1)		
osmium	Os	76	190.23(3)		g
iridium	Ir	77	192.217(3)		
platinum	Pt	78	195.084(9)		
gold	Au	79	196.966 569(5)		
mercury	Hg	80	200.592(3)		
thallium	Tl	81	[204.382, 204.385]	12	
lead	Pb	82	207.2(1)		g r
bismuth*	Bi	83	208.980 40(1)		
polonium*	Po	84	–		
astatine*	At	85	–		
radon*	Rn	86	–		
francium*	Fr	87	–		
radium*	Ra	88	–		
actinium*	Ac	89	–		
thorium*	Th	90	232.0377(4)		g
protactinium*	Pa	91	231.035 88(2)		
uranium*	U	92	238.028 91(3)		g m
neptunium*	Np	93	–		
plutonium*	Pu	94	–		
americium*	Am	95	–		
curium*	Cm	96	–		
berkelium*	Bk	97	–		
californium*	Cf	98	–		
einsteinium*	Es	99	–		
fermium*	Fm	100	–		
mendelevium*	Md	101	–		
nobelium*	No	102	–		
lawrencium*	Lr	103	–		
rutherfordium*	Rf	104	–		

Table 1 (continued)

Element name	Symbol	Atomic number	Standard atomic weight	See also figure	Footnotes
dubnium*	Db	105	–		
seaborgium*	Sg	106	–		
bohrium*	Bh	107	–		
hassium*	Hs	108	–		
meitnerium*	Mt	109	–		
darmstadtium*	Ds	110	–		
roentgenium*	Rg	111	–		
copernicium*	Cn	112	–		
ununtrium*	Uut	113	–		
flerovium*	Fl	114	–		
ununpentium*	Uup	115	–		
livermorium*	Lv	116	–		
ununseptium*	Uus	117	–		
ununoctium*	Uuo	118	–		

*Element has no stable isotopes. One or more representative isotopes are given in Table 4 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 standard-atomic weight being given; the tabulated value and uncertainty should be applicable to normal material.

mass spectrometers without the reliance on any particular mass-fractionation model. Both multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS) and thermal ionization mass spectrometry (TIMS) were employed in the work of Pritzkow *et al.* [45]. The annotation "g" refers to anomalous occurrences at the Oklo natural nuclear reactor in Gabon. Historical values of A_r(Cd) include [44]: 1902, 112.4; 1909, 112.40; 1925, 112.41; 1961, 112.40; 1969, 112.40(1); 1975, 112.41(1); and 1985, 112.411(8).

3.2 Molybdenum

The Commission has changed the recommended value for the standard atomic weight of molybdenum to 95.95(1) from 95.96(2) based on an evaluation published by Mayer and Wieser [46]. The recent evaluation of double-spike mixtures to correct for instrumental mass bias and drift of MC-ICP-MS measurements of NIST SRM 3134 molybdenum standard have revealed a slight bias in the previous value [47], which was based on TIMS measurements. The annotation "g" refers to anomalous occurrences at the Oklo natural nuclear reactor in Gabon. Historical values of A_r(Mo) include [7, 44, 48]: 1902, 96.0; 1938, 95.95; 1961, 95.94; 1969, 95.94(3); 1975, 95.94(1); 2001, 95.94(2); and 2007, 95.96(2).

3.3 Selenium

The Commission has changed the recommended value for the standard atomic weight of selenium, A_r(Se), to 78.971(8) from 78.96(3) based on the work of Wang *et al.* [49] using MC-ICP-MS. This work represents the first mass spectrometric measurement of selenium accepted by the Commission for the basis of the standard atomic weight. Historical values of A_r(Se) include [44]: 1902, 79.1; 1903, 79.2; 1934, 78.96; and 1969, 78.96(3).

3.4 Thorium

The Commission has changed the recommended value for the standard atomic weight of thorium to 232.0377(4) from 232.038 06(2) based on an evaluation of the effect of variation in isotopic abundances in normal materials upon the atomic weight of thorium [50–52]. The revised standard atomic weight reflects the significantly increased abundance of ^{230}Th in deep ocean waters, $x(^{230}\mathrm{Th})$ = (100 to 400) μmol per mol, as compared to the minerals and rocks, $x(^{230}\mathrm{Th})$ = (2 to 10) μmol per mol. Historical values of A_r(Th) include [44, 53]: 1902, 232.5; 1909, 232.42; 1911, 232.4; 1920, 232.15; 1931, 232.12; 1953, 232.05; 1961, 232.038; 1969, 232.0381(1); and 2005, 232.038 06(2).

3.5 Uranium

Although the Commission has not changed the standard atomic weight of uranium since 1999, in 2013 it resolved to clarify the recommended standard atomic weight by reporting the associated standard value for the isotope ratio of uranium in naturally occurring terrestrial materials, $N(^{238}\mathrm{U})/N(^{235}\mathrm{U})$ = 137.8(1).

4 Elements with revised atomic-mass values (aluminium, arsenic, beryllium, caesium, cobalt, fluorine, gold, holmium, manganese, niobium, phosphorus, praseodymium, scandium, thulium, and yttrium)

In normal materials, there are 19 elements whose standard atomic weight is determined by only one isotope, which is also stable (non-radioactive). Thus, the standard atomic weight for these elements is invariant. These elements are: Be, F, Na, Al, P, Sc, Mn, Co, As, Y, Nb, Rh, I, Cs, Pr, Tb, Ho, Tm, and Au. In addition, two elements, Bi and Pa, have only one isotope that contributes to the standard atomic weight, but that isotope is radioactive. The standard atomic weights of these 21 elements are derived directly from their atomic masses.

The 2012 Atomic Mass Evaluation report (AME-2012) contains many advances in the measurement science of atomic masses [15]. The most notable increase in the reported precision of the nuclide masses, which has impact on the atomic-weight values is the 280-fold reduction in the uncertainty of the atomic mass of phosphorus-31. As for the consistency between the values of AME-2003 and AME-2012, the atomic mass of only one stable nuclide, lithium-7, is inconsistent at the 6*s* level of precision, which is the precision used by the Commission to calculate all standard atomic weights of the elements [54]. The AME-2012 report also provides, for the first time, covariances between the atomic-mass estimates. This allows for proper uncertainty evaluation of nuclide mass ratios with denominator other than carbon-12. Revised standard atomic weights are provided for 15 elements for which there have been improvements in the measurement precision of the atomic-mass values since the previous evaluation.

5 Variations in isotopic composition and atomic weights of selected elements

The Commission has provided graphical plots of natural variations in isotopic abundances and atomic weights for all elements whose standard atomic weight is expressed as an interval [10, 43], and these have been updated in Figs. 1 through 12 by addition of isotope-delta axes [24]. These plots may be used to provide information on the likely atomic weight of an element in a given substance. Footnote "m" has been retained for some of these twelve elements to alert the reader that commercial materials can be found that have

undergone undisclosed or inadvertent isotopic fractionation. Examples include NO_x from nitric acid plants, shown in Fig. 5 as a left-pointed arrow and a value of –150 ‰, and carbon dioxide, shown in Fig. 6 as a left-pointing arrow and a value of –229 ‰. Footnotes "g" and "r" no longer apply to these 12 elements [10, 43].

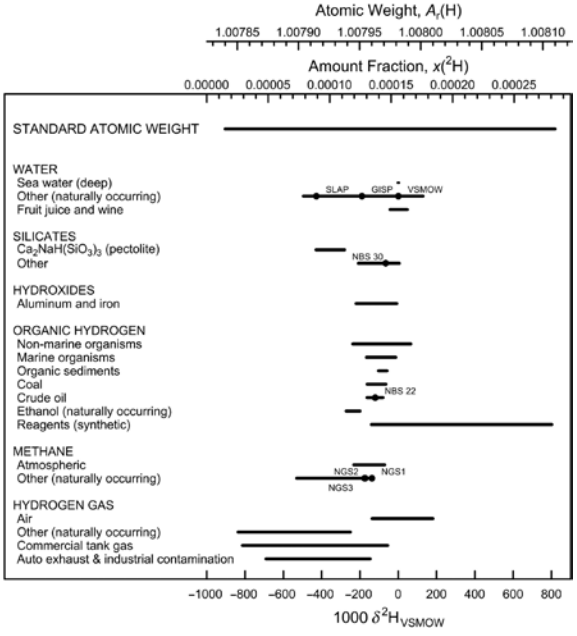

Fig. 1: Variation in isotopic composition and atomic weight of selected hydrogen-bearing materials (modified from [10, 23]). VSMOW is the Vienna Standard Mean Ocean Water–Standard Light Antarctic Precipitation scale [24]. Isotopic reference materials are designated by solid black circles. The δ^2H scale and the ^{2}H amount-fraction scale were matched using the data of Hagemann *et al.* [25]. The expanded uncertainty in matching the atomic-weight and the ^{2}H amount-fraction scales with the δ^2H scale is equivalent to 0.3 ‰.

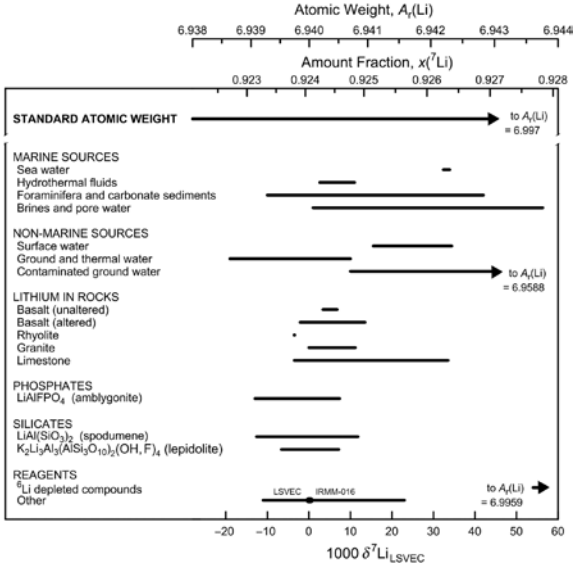

Fig. 2: Variation in isotopic composition and atomic weight of selected lithium-bearing materials (modified from [10, 23]). LSVEC is the lithium carbonate isotopic reference material [26]. Isotopic reference materials are designated by solid black circles. The δ^7Li scale and the ^{7}Li amount-fraction scale were matched using the data of Qi *et al.* [27]. The expanded uncertainty in matching the atomic-weight and ^{7}Li amount-fraction scales with the δ^7Li scale is equivalent to 3 ‰.

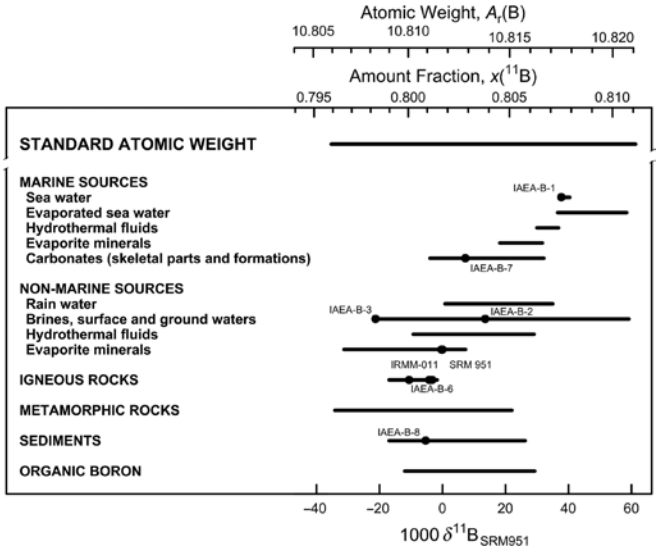

Fig. 3: Variation in isotopic composition and atomic weight of selected boron-bearing materials (modified from [10, 23]). SRM 951 is a boric acid isotopic reference material [26]. Isotopic reference materials are designated by solid black circles. The δ^{11}B scale and ^{11}B amount-fraction scale were matched using the data of Catanzaro *et al*. [28]. The expanded uncertainty in matching the atomic-weight and ^{11}B amount-fraction scales with the δ^{11}B scale is equivalent to 0.8 ‰.

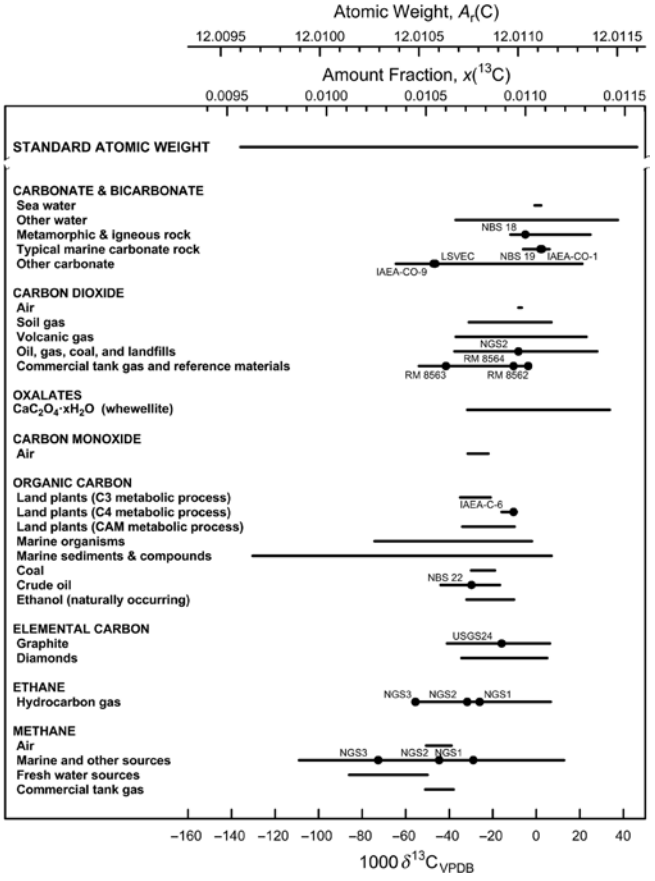

Fig. 4: Variation in isotopic composition and atomic weight of selected carbon-bearing materials (modified from [10, 23]). VPDB is the Vienna Peedee belemnite–LSVEC isotope scale [24]. Isotopic reference materials are designated by solid black circles. The δ^{13}C scale and ^{13}C amount-fraction scale were matched using the data of Chang and Li [18]. The expanded uncertainty in matching the atomic-weight and ^{13}C amount-fraction scales with the δ^{13}C scale is equivalent to 2.5 ‰.

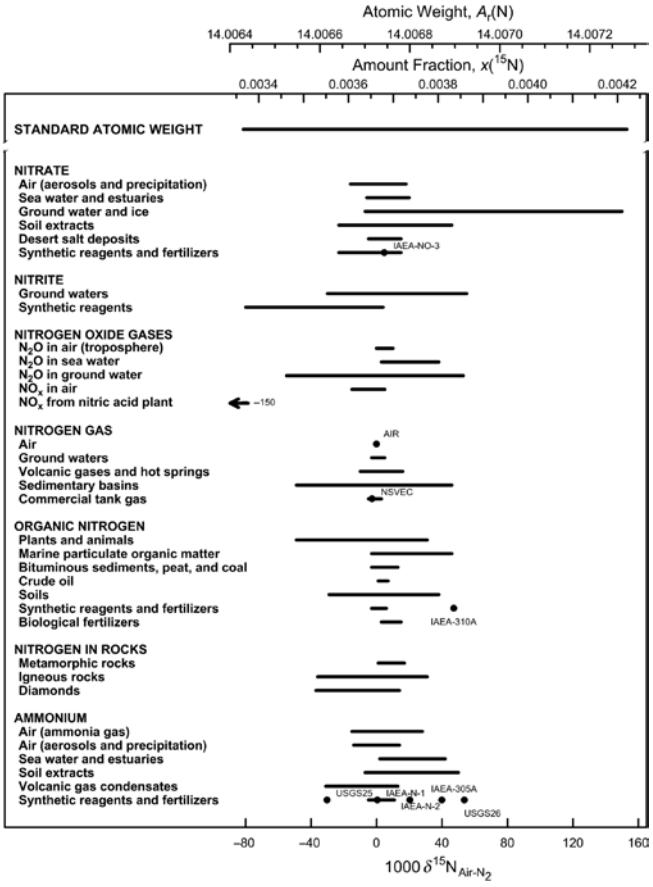

Fig. 5: Variation in isotopic composition and atomic weight of selected nitrogen-bearing materials (modified from [10, 23]). Isotopic reference materials are designated by solid black circles. The δ^{15}N scale and ^{15}N amount-fraction scale were matched using the data of Junk and Svec [29]. The expanded uncertainty in the atomic-weight and ^{15}N amount-fraction scales with the δ^{15}N scale is equivalent to 1.1 ‰.

6 Abridged table of standard atomic weights

The number of significant digits reported in the full Table of Standard Atomic Weights (Table 1) exceeds the needs and the interests of many users. In the past, tables abridged to four and five significant digits have been published with the expectation that subsequent changes to the abridged values will be minimal. Noting that the truncation errors introduced in the four-significant digit table are unacceptable, the Commission resolved that five-digit table is a more appropriate form of abridged representation. Standard atomic weights abridged to five significant digits are presented in Table 2. 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 7.

7 Conventional atomic-weight values for selected elements

The Commission recognizes that some users of atomic-weight data only need single values with disregard to their uncertainties. Therefore, for those elements with standard atomic weights given as intervals, the Commission provides conventional atomic-weight values (Table 3). These conventional quantity values 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.

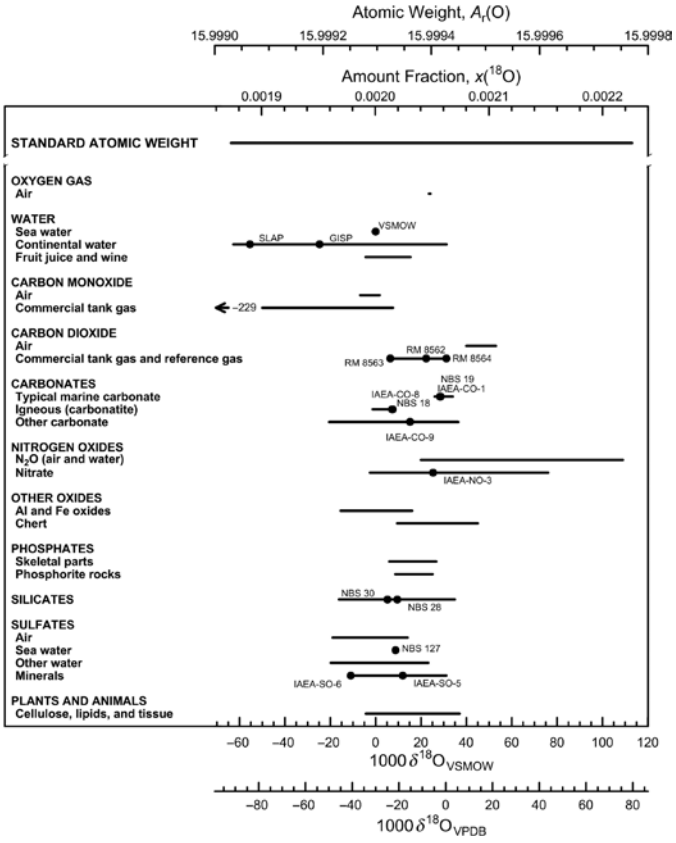

Fig. 6: Variation in isotopic composition and atomic weight composition of selected oxygen-bearing materials (modified from [10, 23]). VSMOW is the Vienna Standard Mean Ocean Water–Standard Light Antarctic Precipitation scale [24] and VPDB is the Vienna Peedee belemnite–LSVEC isotope scale [24]. Isotopic reference materials are designated by solid black circles. The $\delta^{18}O$ scale (or $\delta^{18/16}O$ scale, for completeness) and ^{18}O amount-fraction scale were matched using the data of Li *et al.* [30] and Baertschi [31]. The expanded uncertainty in the atomic-weight and ^{18}O amount-fraction scales with the $\delta^{18}O$ scale is equivalent to 0.3 ‰.

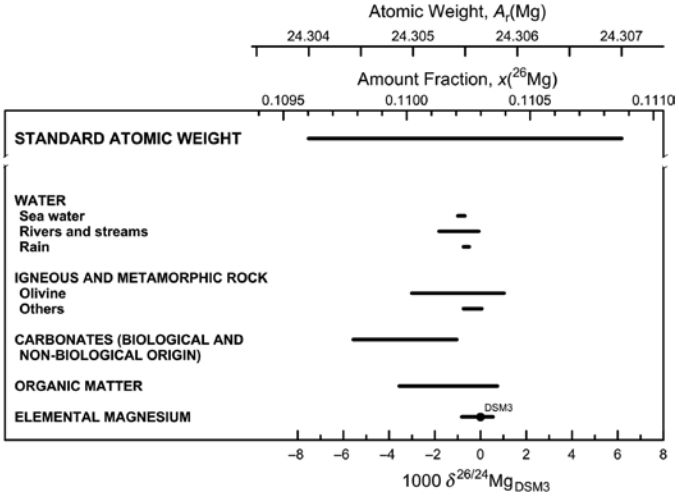

Fig. 7: Variation in isotopic composition and atomic weight of magnesium in selected magnesium-bearing materials (modified from [23, 43]). The $\delta^{26/24}Mg$ measurements are expressed relative to the reference material DSM3 because many materials were measured relative to it [32]. However, DSM3 is not recommended as the international measurement standard for the $\delta^{26/24}Mg$ scale because the supply is exhausted. The $\delta^{26/24}Mg$ scale and ^{26}Mg amount-fraction scales were matched using data from [32]. The expanded uncertainty in matching the atomic-weight and ^{26}Mg amount-fraction scales with the $\delta^{26/24}Mg$ scale is equivalent to 1.1 ‰.

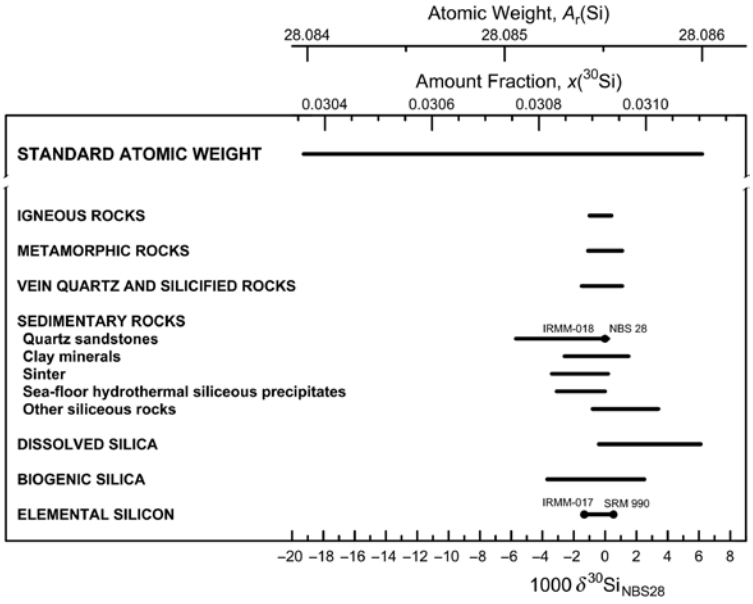

Fig. 8: Variation in isotopic composition and atomic weight of selected silicon-bearing materials (modified from [10, 23]). The isotopic reference material NBS 28 is optical quartz [26]. Isotopic reference materials are designated by solid black circles. The δ^{30}Si scale (or $\delta^{30/28}$Si scale, for completeness) and ^{30}Si amount-fraction scale were matched using the data of De Bièvre *et al.* [33] and a δ^{30}Si value for IRMM-017 of –1.3 ‰ relative to NBS 28 [26]. The expanded uncertainty in the atomic-weight and ^{30}Si amount-fraction scales with the δ^{30}Si scale is equivalent to 0.23 ‰.

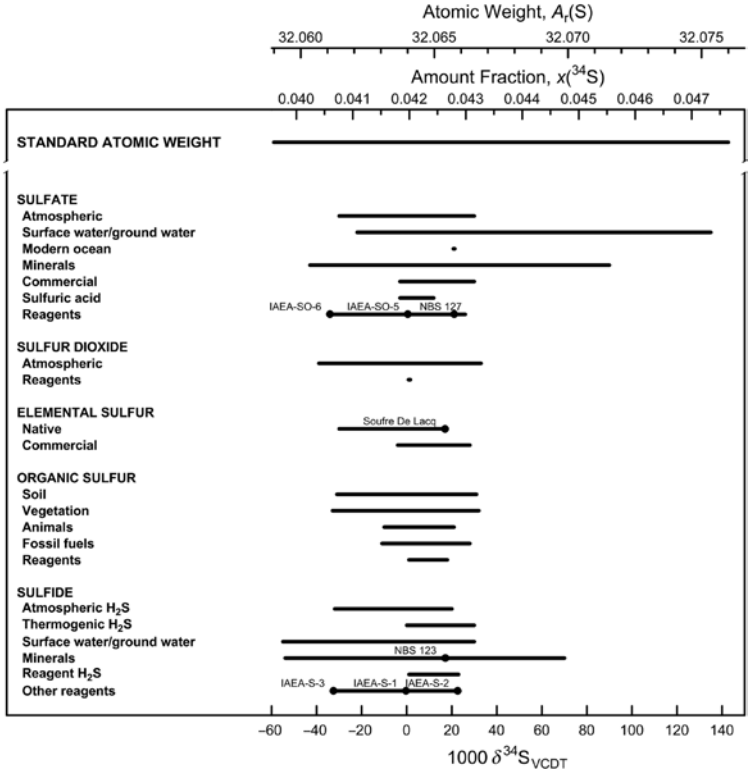

Fig. 9: Variation in isotopic composition and atomic weight of selected sulfur-bearing materials (modified from [10, 23]). VCDT is Vienna Cañon Diablo troilite [26]. Isotopic reference materials are designated by solid black circles. The δ^{34}S scale (or $\delta^{34/32}$S scale, for completeness) and ^{34}S amount-fraction scale were matched using the data of Ding *et al.* [34]. The expanded uncertainty in the atomic-weight and ^{34}S amount-fraction scales with the δ^{34}S scale is equivalent to 0.2 ‰.

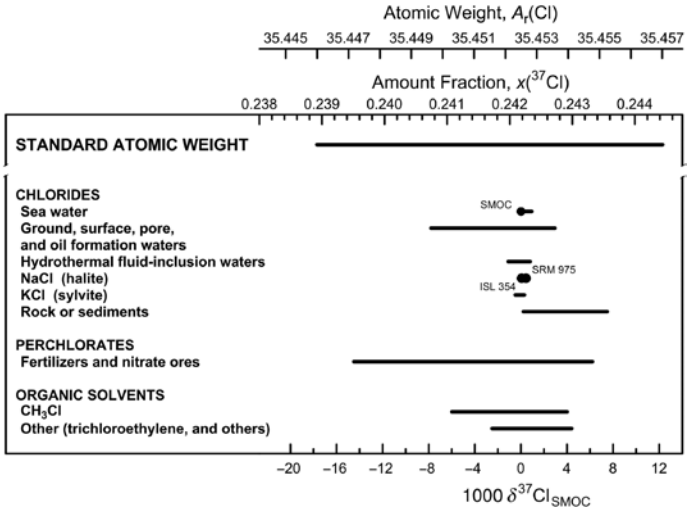

Fig. 10: Variation in isotopic composition and atomic weight of selected chlorine-bearing materials (modified from [10, 23]). SMOC is Standard Mean Ocean Chloride [26]. Isotopic reference materials are designated by solid black circles. The δ^{37}Cl scale and the ^{37}Cl amount-fraction scale were matched using the data of Shields *et al*. [35] and Xiao *et al*. [36]. The expanded uncertainty in the atomic-weight and ^{37}Cl amount-fraction scales with the δ^{37}Cl scale is equivalent to 2.5 ‰.

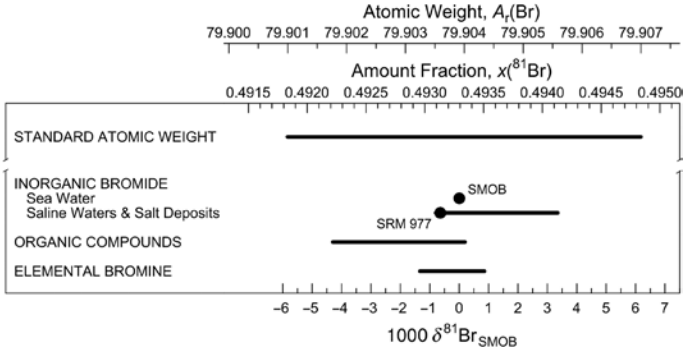

Fig. 11: Variation in isotopic composition and atomic weight of bromine in selected bromine-bearing materials (modified from [10]). SMOB is Standard Mean Ocean Bromide [24]. Isotopic reference materials are designated by solid black circles. The δ^{81}Br scale and the ^{81}Br amount-fraction scale were matched using data from [37, 38]. The expanded uncertainty in matching the atomic-weight and ^{81}Br amount-fraction scales with the δ^{81}Br scale is equivalent to 1.1 ‰.

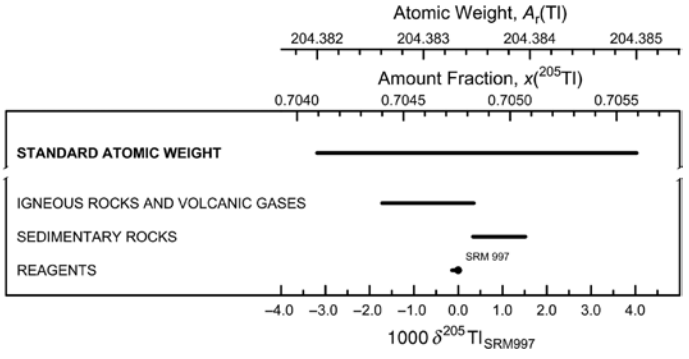

Fig. 12: Variation in atomic weight with isotopic composition of selected thallium-bearing materials (modified from [10, 23]. The reference material SRM 997 is elemental thallium metal [26]. An isotopic reference material is designated by a solid black circle. The δ^{205}Tl scale and the ^{205}Tl amount-fraction scale were matched using the data of Dunstan *et al*. [39] and Rosman and Taylor [40]. The expanded uncertainty in the atomic-weight and ^{205}Tl amount-fraction scales with the δ^{205}Tl scale is equivalent to 0.4 ‰.

Table 2: Standard atomic weights 2013 abridged to five significant digits. Atomic weights are 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 and symbols 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 officially named.

Element name	Symbol	Atomic number	Abridged standard atomic weight	Footnotes
hydrogen	H	1	[1.0078, 1.0082]	m
helium	He	2	4.0026	
lithium	Li	3	[6.938, 6.997]	m
beryllium	Be	4	9.0122	
boron	B	5	[10.806, 10.821]	m
carbon	C	6	[12.009, 12.012]	
nitrogen	N	7	[14.006, 14.008]	m
oxygen	O	8	[15.999, 16.000]	m
fluorine	F	9	18.998	
neon	Ne	10	20.180	m
sodium	Na	11	22.990	
magnesium	Mg	12	[24.304, 24.307]	
aluminium (aluminum)	Al	13	26.982	
silicon	Si	14	[28.084, 28.086]	
phosphorus	P	15	30.974	
sulfur	S	16	[32.059, 32.076]	
chlorine	Cl	17	[35.446, 35.457]	m
argon	Ar	18	39.948	g r
potassium	K	19	39.098	
calcium	Ca	20	40.078(4)	g
scandium	Sc	21	44.956	
titanium	Ti	22	47.867	
vanadium	V	23	50.942	
chromium	Cr	24	51.996	
manganese	Mn	25	54.938	
iron	Fe	26	55.845(2)	
cobalt	Co	27	58.933	
nickel	Ni	28	58.693	r
copper	Cu	29	63.546(3)	r
zinc	Zn	30	65.38(2)	r
gallium	Ga	31	69.723	
germanium	Ge	32	72.630(8)	
arsenic	As	33	74.922	
selenium	Se	34	78.971(8)	r
bromine	Br	35	[79.901, 79.907]	
krypton	Kr	36	83.798(2)	g m
rubidium	Rb	37	85.468	g
strontium	Sr	38	87.62	g r
yttrium	Y	39	88.906	
zirconium	Zr	40	91.224(2)	g
niobium	Nb	41	92.906	
molybdenum	Mo	42	95.95	g
technetium*	Tc	43	–	
ruthenium	Ru	44	101.07(2)	g
rhodium	Rh	45	102.91	

Table 2 (continued)

Element name	Symbol	Atomic number	Abridged standard atomic weight	Footnotes
palladium	Pd	46	106.42	g
silver	Ag	47	107.87	g
cadmium	Cd	48	112.41	g
indium	In	49	114.82	
tin	Sn	50	118.71	g
antimony	Sb	51	121.76	g
tellurium	Te	52	127.60(3)	g
iodine	I	53	126.90	
xenon	Xe	54	131.29	g m
caesium (cesium)	Cs	55	132.91	
barium	Ba	56	137.33	
lanthanum	La	57	138.91	
cerium	Ce	58	140.12	g
praseodymium	Pr	59	140.91	
neodymium	Nd	60	144.24	g
promethium*	Pm	61	–	
samarium	Sm	62	150.36(2)	g
europium	Eu	63	151.96	g
gadolinium	Gd	64	157.25(3)	g
terbium	Tb	65	158.93	
dysprosium	Dy	66	162.50	g
holmium	Ho	67	164.93	
erbium	Er	68	167.26	g
thulium	Tm	69	168.93	
ytterbium	Yb	70	173.05	g
lutetium	Lu	71	174.97	g
hafnium	Hf	72	178.49(2)	
tantalum	Ta	73	180.95	
tungsten	W	74	183.84	
rhenium	Re	75	186.21	
osmium	Os	76	190.23(3)	g
iridium	Ir	77	192.22	
platinum	Pt	78	195.08	
gold	Au	79	196.97	
mercury	Hg	80	200.59	
thallium	Tl	81	[204.38, 204.39]	
lead	Pb	82	207.2	g r
bismuth*	Bi	83	208.98	
polonium*	Po	84	–	
astatine*	At	85	–	
radon*	Rn	86	–	
francium*	Fr	87	–	
radium*	Ra	88	–	
actinium*	Ac	89	–	
thorium*	Th	90	232.04	g
protactinium*	Pa	91	231.04	
uranium*	U	92	238.03	g m
neptunium*	Np	93	–	
plutonium*	Pu	94	–	
americium*	Am	95	–	
curium*	Cm	96	–	
berkelium*	Bk	97	–	
californium*	Cf	98	–	

Table 2 (continued)

Element name	Symbol	Atomic number	Abridged standard atomic weight	Footnotes
einsteinium*	Es	99	–	
fermium*	Fm	100	–	
mendelevium*	Md	101	–	
nobelium*	No	102	–	
lawrencium*	Lr	103	–	
rutherfordium*	Rf	104	–	
dubnium*	Db	105	–	
seaborgium*	Sg	106	–	
bohrium*	Bh	107	–	
hassium*	Hs	108	–	
meitnerium*	Mt	109	–	
darmstadtium*	Ds	110	–	
roentgenium*	Rg	111	–	
copernicium*	Cn	112	–	
ununtrium*	Uut	113	–	
flerovium*	Fl	114	–	
ununpentium*	Uup	115	–	
livermorium*	Lv	116	–	
ununseptium*	Uus	117	–	
ununoctium*	Uuo	118	–	

*Element has no stable isotopes. One or more representative isotopes are given in Table 4 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 standard atomic weight being given; the tabulated value and uncertainty should be applicable to normal material.

Table 3: Conventional atomic weights. For users needing an atomic-weight value for an unspecified sample with disregard to the uncertainty, such as for trade and commerce, the following conventional values are provided. Atomic weights are scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.

Element name	Symbol	Atomic number	Conventional atomic weight
hydrogen	H	1	1.008
lithium	Li	3	6.94
boron	B	5	10.81
carbon	C	6	12.011
nitrogen	N	7	14.007
oxygen	O	8	15.999
magnesium	Mg	12	24.305
silicon	Si	14	28.085
sulfur	S	16	32.06
chlorine	Cl	17	35.45
bromine	Br	35	79.904
thallium	Tl	81	204.38

Table 4: Relative atomic masses and half-lives of selected radioactive nuclides.

Atomic number	Element name[a]	Symbol	Mass number[b]	Atomic mass/Da[c]	Half-life[d]
19	potassium	K	40*	39.963 9982(4)	$1.248(3) \times 10^{9}$ a
20	calcium	Ca	48*	47.952 5228(8)	$5.3(1.7) \times 10^{19}$ a
23	vanadium	V	50*	49.947 156(6)	$1.5(4) \times 10^{17}$ a
32	germanium	Ge	76*	75.921 4027(2)	$1.58(17) \times 10^{21}$ a
34	selenium	Se	82*	81.916 700(9)	$9.7(5) \times 10^{19}$ a
37	rubidium	Rb	87*	86.909 180 53(5)	$4.923(22) \times 10^{10}$ a
40	zirconium	Zr	96*	95.908 27(2)	$2.0(4) \times 10^{19}$ a
42	molybdenum	Mo	100*	99.907 472(7)	$7.3(4) \times 10^{18}$ a
43	technetium	Tc	97	96.906 37(3)	$4.21(16) \times 10^{6}$ a
			98	97.907 21(3)	$4.2(3) \times 10^{6}$ a
			99	98.906 251(6)	$2.111(12) \times 10^{5}$ a
48	cadmium	Cd	113*	112.904 408(3)	$8.04(5) \times 10^{15}$ a
			116*	115.904 763(1)	$3.0(4) \times 10^{19}$ a
49	indium	In	115*	114.903 878 78(8)	$4.41(25) \times 10^{14}$ a
52	tellurium	Te	128*	127.904 461(6)	$2.2(3) \times 10^{24}$ a
			130*	129.906 222 75(8)	$7.9(1.0) \times 10^{20}$ a
54	xenon	Xe	136*	135.907 214 48(7)	$>10 \times 10^{21}$ a
56	barium	Ba	130*	129.906 32(2)	$>4 \times 10^{21}$ a
57	lanthanum	La	138*	137.907 12(3)	$1.02(1) \times 10^{11}$ a
60	neodymium	Nd	144*	143.910 09(2)	$2.29(16) \times 10^{15}$ a
			150*	149.920 90(2)	$6.7(7) \times 10^{18}$ a
61	promethium	Pm	145	144.912 76(2)	17.7(4) a
			146	145.914 70(3)	5.53(5) a
			147	146.915 15(2)	2.6234(2) a
62	samarium	Sm	147*	146.914 90(2)	$1.066(7) \times 10^{11}$ a
			148*	147.914 83(2)	$7(3) \times 10^{15}$ a
71	lutetium	Lu	176*	175.942 69(2)	$3.76(7) \times 10^{10}$ a
72	hafnium	Hf	174*	173.940 05(2)	$2.0(4) \times 10^{15}$ a
74	tungsten	W	180*	179.946 71(2)	$1.8(2) \times 10^{18}$ a
75	rhenium	Re	187*	186.955 75(1)	$4.33(7) \times 10^{10}$ a
76	osmium	Os	186*	185.953 84(1)	$2.0(1.1) \times 10^{15}$ a
78	platinum	Pt	190*	189.959 93(4)	$6.5(3) \times 10^{11}$ a
83	bismuth	Bi	209*	208.980 40(1)	$1.99(7) \times 10^{19}$ a
84	polonium	Po	208	207.981 25(2)	2.898(2) a
			209	208.982 43(2)	102(5) a
			210	209.982 874(8)	138.376(2) d
85	astatine	At	210	209.987 15(5)	8.1(4) h
			211	210.987 50(2)	7.214(7) h
86	radon	Rn	210	209.989 69(3)	2.4(1) h
			211	210.990 60(5)	14.6(2) h
			222	222.017 58(2)	3.8235(3) d
87	francium	Fr	212	211.996 23(6)	20.0(6) min
			222	222.0176(2)	14.2(3) min
			223	223.019 74(2)	22.00(7) min
88	radium	Ra	226	226.025 41(2)	$1.600(7) \times 10^{3}$ a
			228	228.031 07(2)	5.75(3) a
89	actinium	Ac	225	225.023 23(3)	9.920(3) d
			227	227.027 75(2)	21.772(3) a
90	thorium	Th	230*	230.033 13(2)	$7.54(3) \times 10^{4}$ a
			232*	232.038 06(2)	$1.40(1) \times 10^{10}$ a
91	protactinium	Pa	231*	231.035 88(2)	$3.276(11) \times 10^{4}$ a
			233	233.040 25(2)	26.975(13) d
92	uranium	U	233	233.039 64(2)	$1.592(2) \times 10^{5}$ a
			234*	234.040 95(2)	$2.455(6) \times 10^{5}$ a
			235*	235.043 93(2)	$7.04(1) \times 10^{8}$ a
			236	236.045 57(2)	$2.342(3) \times 10^{7}$ a
			238*	238.050 79(2)	$4.468(3) \times 10^{9}$ a

Table 4 (continued)

Atomic number	Element name[a]	Symbol	Mass number[b]	Atomic mass/Da[c]	Half-life[d]
93	neptunium	Np	236	236.0466(3)	$1.53(5) \times 10^5$ a
			237	237.048 17(2)	$2.144(7) \times 10^6$ a
94	plutonium	Pu	238	238.049 56(2)	87.7(1) a
			239	239.052 16(2)	$2.411(3) \times 10^4$ a
			240	240.053 81(2)	$6.561(7) \times 10^3$ a
			241	241.056 85(2)	14.290(6) a
			242	242.058 74(2)	$3.75(2) \times 10^5$ a
			244	244.064 21(4)	$8.00(9) \times 10^7$ a
95	americium	Am	241	241.056 83(2)	432.6(6) a
			243	243.061 38(2)	$7.37(4) \times 10^3$ a
96	curium	Cm	243	243.061 39(2)	29.1(1) a
			244	244.062 75(2)	18.10(2) a
			245	245.065 49(2)	$8.423(74) \times 10^3$ a
			246	246.067 22(2)	$4.706(40) \times 10^3$ a
			247	247.070 35(3)	$1.56(5) \times 10^7$ a
			248	248.072 19(4)	$3.48(6) \times 10^5$ a
97	berkelium	Bk	247	247.070 31(4)	$1.38(25) \times 10^3$ a
			249	249.074 99(2)	330(4) d
98	californium	Cf	249	249.074 85(2)	351(2) a
			250	250.076 41(2)	13.08(9) a
			251	251.079 59(3)	$9.0(4) \times 10^2$ a
			252	252.081 63(4)	2.645(8) a
99	einsteinium	Es	252	252.0830(3)	472(2) d
			254	254.088 02(3)	275.7(5) d
100	fermium	Fm	253	253.085 19(3)	3.00(12) d
			257	257.095 11(5)	100.5(2) d
101	mendelevium	Md	258	258.098 43(3)	51.5(3) d
			260	260.104(2)	27.8(8) d
102	nobelium	No	255	255.0932(1)	3.52(18) min
			259	259.1010(7)	58(5) min
103	lawrencium	Lr	261	261.107(2)	39(12) min
			262	262.110(2)	4 h
104	rutherfordium	Rf	265	265.117(3)	6.6(5.3) min
			267	267.122(4)	2.5(1.5) h
105	dubnium	Db	268	268.126(4)	30.8(5.0) h
			270	270.131(4)	90(70) h
106	seaborgium	Sg	269	269.129(3)	8.0(6.3) min
			271	271.134(4)	3.1(1.6) min
107	bohrium	Bh	270	270.133(2)	3.8(3.0) min
			274	274.144(4)	3.4(2.7) min
108	hassium	Hs	269	269.1338(8)	27(17) s
			270	270.134(2)	~30 s
109	meitnerium	Mt	276	276.152(4)	0.73(16) s
			278	278.156(5)	29(23) s
110	darmstadtium	Ds	280	280.161(6)	11(6) s
			281	281.165(4)	14(4) s
111	roentgenium	Rg	281	281.166(6)	37(17) s
			282	282.169(5)	1.9(1.5) s
112	copernicium	Cn	283	283.173(4)	4.1(1.0) s
			285	285.177(4)	32(9) s
113	ununtrium	Uut	285	285.180(6)	8(4) s
			286	286.182(5)	70(60) s
114	flerovium	Fl	287	287.187(4)	0.52(13) s
			288	288.188(6)	0.75(14) s
			289	289.190(4)	2.4(6) s

Table 4 (continued)

Atomic number	Element name[a]	Symbol	Mass number[b]	Atomic mass/Da[c]	Half-life[d]
115	ununpentium	Uup	288	288.193(4)	0.19(4) s
			289	289.194(6)	0.34(18) s
			290	290.196(5)	60(50) ms
116	livermorium	Lv	291	291.201(4)	28(15) ms
			292	292.202(6)	24(12) ms
			293	293.204(4)	80(40) ms
117	ununseptium	Uus	293	293.208(6)	18(8) ms
			294	294.210(5)	0.29(23) ms
118	ununoctium	Uuo	294	294.214(5)	1.4(7) ms

[a]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. Listing of particular isotopes for these elements does not imply any priority of the discovery of these elements on the part of IUPAC or the Commission.
[b]Long-lived radioactive isotopes of elements with a characteristic terrestrial isotopic composition that contribute to the standard atomic weight determinations are marked with an asterisk. Selected radioactive isotopes for elements with no stable isotopes, with no characteristic isotopic composition, and with no standard atomic weight are also presented.
[c]Atomic masses of nuclides are expressed in daltons (symbol, Da), which is 1/12 mass of a single carbon-12 atom (neutral, in its electronic and nuclear ground state, and at rest), also called the unified atomic mass unit (symbol, u).
[d]Standard symbols are used for units of time: a = year; d = day; h = hour; min = minute; s = second; ms = millisecond.
*Indicates isotope contributing to the determination of a standard atomic weight.

8 Relative atomic masses 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 compiled in Table 4. Long-lived radioactive isotopes of elements with a characteristic terrestrial isotopic composition that contribute to the standard atomic weight determinations are marked with an asterisk (*) 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. 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 commercial relevance have been applied in the past. The Commission has no official responsibility for the dissemination of atomic masses and half-life values and the information contained in this table will enable to calculate atomic weights of radioactive materials with a variety of isotopic compositions. Atomic masses are taken from 2012 Atomic Mass Evaluation report [15]. However, the uncertainty of atomic masses is not taken as reported. Rather, all uncertainty estimates are expanded by a factor of six in order to conform to the conservative reporting practices of the Commission. The half-life values are quoted with uncertainties at the one standard deviation level and are taken from the NUBASE2012 report [55].

9 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 developed a Periodic Table of the Isotopes [14]. The goal of this IUPAC-sponsored project is to produce learner-

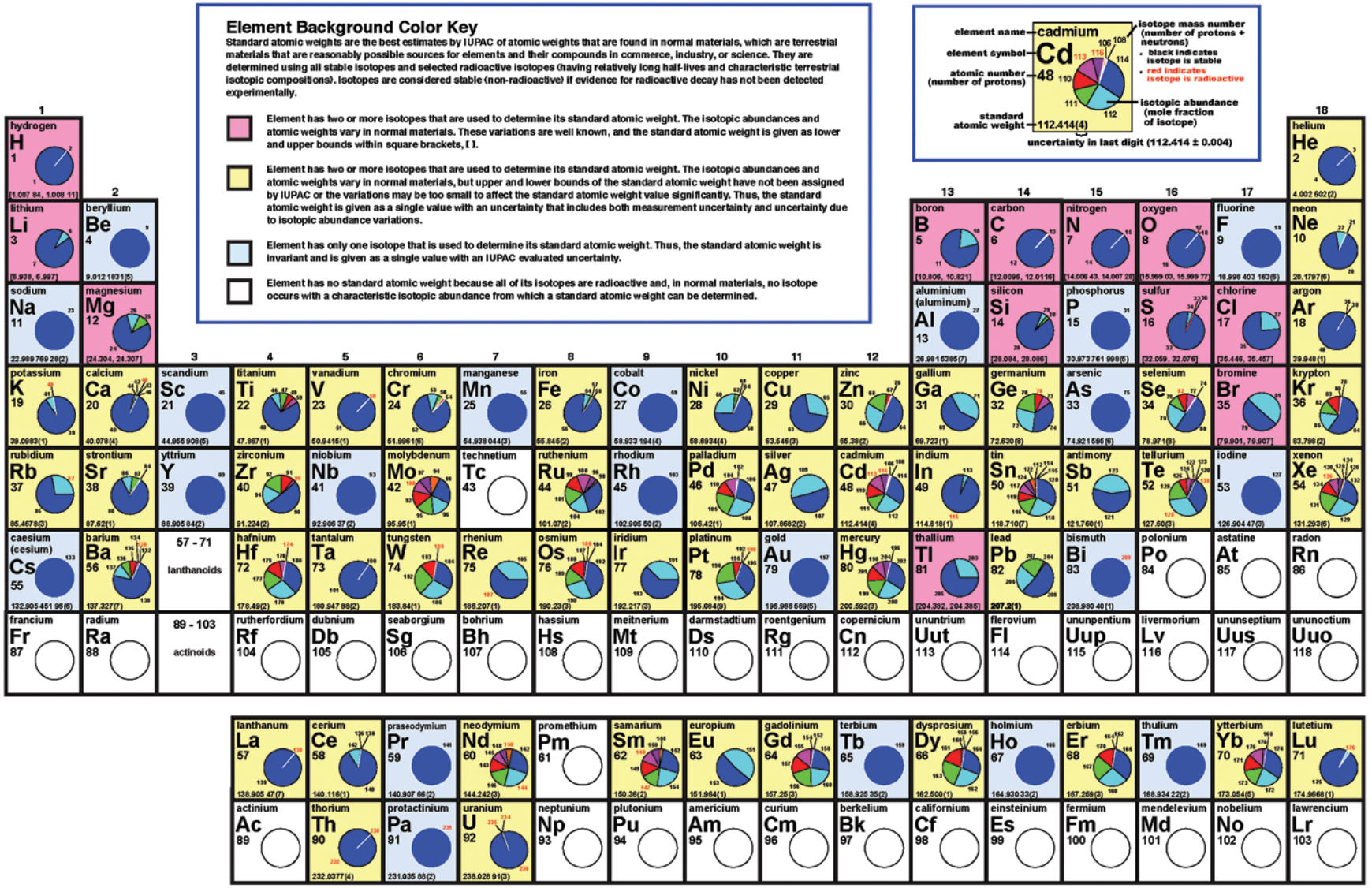

Fig. 13: IUPAC Periodic Table of the Isotopes, 1 October 2013.

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 and examples of applications of isotopes in science, industry and everyday life.

The IUPAC Periodic Table of the Isotopes produced by members of the task group, shown in Fig. 13, employs colored tiles to distinguish among four categories of the elements:

1. **pink**: 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;
2. **yellow**: 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;
3. **blue**: element with only one isotope that is used to determine the standard atomic weight, which is invariant;
4. **white**: 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 from which a standard atomic weight can be determined.

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. Radioactive nuclides are identified with red mass numbers. Note, however, that the IUPAC Periodic Table of the Isotopes determines the radioactivity of nuclides independently from the most recent published data. Consequently, minor discrepancies between this table and the NUBASE2012 might occur, such as the firmly-established radioactivity of ^{130}Ba and ^{136}Xe, which is not reflected in NUBASE2012.

10 Membership of sponsoring bodies

Membership of the Inorganic Chemistry Division Committee for the period 2012–2013 was as follows: ***President:*** R. D. Loss (Australia); ***Secretary:*** M. Leskelä (Finland); ***Vice President:*** J. Reedijk (Netherlands); ***Titular Members:*** M. Drábik (Slovakia); N. E. Holden (USA); P. Karen (Norway); S. Mathur (Germany); L. R. Öhrström (Sweden); K. Sakai (Japan); E. Y. Tshuva (Israel); ***Associate Members:*** J. Buchweishaija (Tanzania); T. Ding (China); J. Garcia-Martinez (Spain); D. Rabinovich (USA); A. Kilic (Turkey); R.-N. Vannier (France); ***National Representatives:*** F. Abdul Aziz (Malaysia); S. Ali (Pakistan); V. Chandrasekhar (India); B. Prugovecki (Croatia); H. E. Toma (Brazil); N. Trendafilova (Bulgaria); S. Youngme (Thailand).
Membership of the Commission on Isotopic Abundances and Atomic Weights for the period 2012–2013 was as follows:
Chair: W. A. Brand (Germany); ***Secretary:*** J. Meija (Canada); ***Titular Members:*** M. Gröning (Austria); T. Hirata (Japan), T. Prohaska (Austria); R. Schönberg (Germany); ***Associate Members:*** M. Berglund (Belgium); G. O'Connor nee Singleton (USA); M. Wieser (Canada); X. K. Zhu (China). ***National Representatives:*** T. B. Coplen (USA); P. De Bièvre (Belgium). ***Ex-officio:*** R. D. Loss (Australia).

11 In memoriam: Norman N. Greenwood (1925–2012)

The Commission notes the death of a former Chairman of the Commission. Prof Norman Greenwood, FRSC, best known for his seminal textbook *Chemistry of the Elements* (with Alan Earnshaw). Norman Neill Greenwood (Fig. 14) was born on 19 January 1925 in Melbourne (Australia) and died on 14 November 2012 in Leeds (Yorkshire) at age 87 [56].

Throughout his scientific carrier Greenwood made significant contributions in science, most notably in the development of Mössbauer spectroscopy and in the chemistry of boron hydrides. In 1963 Greenwood attended his first meeting of the Commission and he was elected a member. During the 1967 meeting, which

Fig. 14: Norman Neill Greenwood (Courtesy of Linda Quilici).

was transacted entirely by mail, Greenwood was elected chairman of the Commission. After serving as Chairman of the Commission, Greenwood became President of the IUPAC Inorganic Division Committee. Norman Greenwood was a Fellow of the Royal Society, a Foreign Member of the French Academy of Sciences, and he played a key role in establishing the criteria for recognizing the discovery of new elements, which now form an integral part of the IUPAC.

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