Atomic Weights of the Elements 1993

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IUPAC Commission on Atomic Weights and Isotopic Abundances

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IUPAC Commission on Atomic Weights and Isotopic Abundances
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The biennial review of atomic weight, A_r(E), determinations and other cognate data has resulted in changes for the standard atomic weight of titanium from 47.88±0.03 to 47.867±0.001, of iron from 55.847±0.003 to 55.845±0.002, of antimony from 121.757±0.003 to 121.760±0.001, and of iridium from 192.22±0.03 to 192.217±0.003. Recent investigations on chlorine and bromine confirmed the presently accepted values of A_r(Cl) and A_r(Br). To emphasize the fact that the atomic weight of lithium commonly available in laboratory reagents can vary significantly, the value of lithium, A_r(Li), was enclosed in brackets and a footnote was added. As a result of several changes, the Table of Standard Atomic Weights Abridged to Five Significant Figures has been updated. Because relative isotope-ratio data for stable hydrogen, carbon, and oxygen are commonly being expressed on non-corresponding scales, the Commission recommends that such isotopic data be expressed only relative to the references VSMOW and VPDB. Because many elements have a different isotopic composition in some non-terrestrial materials, recent data on non-terrestrial materials are included in this report for the information of the interested scientific community. ©*1995 American Institute of Physics and American Chemical Society.*

Key words: atomic weight; critical evaluation; elements; isotopic compositions.

Contents

List of Tables

List of Figures

1. Introduction

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Professor K. G. Heumann from 6^{th}–8^{th} August 1993, during the 37^{th} IUPAC General Assembly in Lisbon, Portugal. The Commission decided to publish the report "Atomic Weights of the Elements 1993" as presented here.

The Commission has reviewed the literature over the previous two years since the last report[1] and evaluated the published data on atomic weights and isotopic compositions on an element-by-element basis. The atomic weight of an element (Tables 1 and 2) can be determined from a knowledge of the isotopic abundances and corresponding atomic masses of the nuclides of that element. The latest compilation of the isotopic abundances and atomic masses with all relevant data was published in 1991,[2] and 1985,[3] respectively. The Commission periodically reviews the history of the atomic weight of each element emphasizing the relevant published scientific evidence on which decisions have been made.[4]

Membership of the Commission for the period 1991–1993 was as follows: K. G. Heumann (FRG, *Chairman*); T. B. Coplen (USA, *Secretary*); H. J. Dietze (FRG, Associate); M. Ebihara (Japan, Associate); J. W. Gramlich (USA, Titular); H. S. Hertz (USA, Associate); H. R. Krouse (Canada, Titular); R. D. Loss (Australia, Associate); G. Ramendik (Russia, Associate); K. J. R. Rosman (Australia, Titular); L. Schultz (FRG, Associate); M. Shima (Japan, Titular); P. Taylor (Belgium, Associate); L. Turpin (France, Associate); K. Wade (UK, Titular); P. De Bièvre (Belgium, National Representative); E. Giesbrecht (Brazil, National Representative); N. N. Greenwood (UK, National Representative); D. Richardson, (USA, National Representative); Y. Xiao (China, National Representative).

2. Comments on Some Atomic Weights and Annotations

2.1. Titanium

The Commission has changed the recommended value for the standard atomic weight of titanium to $A_r(Ti) = 47.867(1)$ based on the calibrated positive thermal ionization mass-spectrometric determination by Shima and Torigoye.[5] The previous value, $A_r(Ti) = 47.88(3)$, was based on recalculation of the chemical[6,7] and the available mass-spectrometric determinations,[8,9,10,11,12,13] but was weighted towards the calibrated mass-spectrometric measurements of Belsheim.[13] Although highly precise mass-spectrometric determinations by Heydegger *et al.*,[14] Niederer *et al.*[15] and Niemeyer and Lugmair[16] have been published since 1979, none of those were calibrated measurements. Therefore, the Commission retained the previous values of $A_r(Ti)$ and its uncertainty. Historical values of $A_r(Ti)$ [values before 1961 are based on $A_r(O) = 16$ exactly; more recent values are concordant with $A_r(O) = 15.9994$] include: 1894, 48; 1896, 48.15; 1903, 48.1; 1927, 47.90; 1969, 47.90(3); and 1979, 47.88(3).

It should be noted that the two calibrated measurements by Shima and Torigoye[5] and Belsheim[13] show excellent agreement. Titanium is an abundant, widely distributed element, yet the previous value of $A_r(Ti)$ carried the relative uncertainty of 6.3×10^{-4}. This uncertainty was the result of instrumental difficulties with titanium and not because of natural isotopic variability. Hogg[11] and Belsheim[13] searched for, but found no measurable variability in the isotopic composition of terrestrial titanium. Furthermore, recent investigations have not detected any variations in isotopic abundance in meteorites[14,15,16,17,18,19].

2.2. Iron

The Commission has changed the recommended value for the standard atomic weight of iron to $A_r(Fe) = 55.845(2)$ based on recent calibrated positive thermal ionization mass-spectrometric measurements carried out on a metallic iron sample of high purity by Taylor *et al.*[20] The magnitude of the uncertainty on this value is mainly due to the variations of iron isotopic composition found by Dixon *et al.*[21] in geological and biological samples. The previous value of $A_r(Fe) = 55.847(3)$ was assigned in 1961,[22] based on mass-spectrometric measurements. Historical values of $A_r(Fe)$ [values before 1961 are based on $A_r(O) = 16$ exactly; more recent values are concordant with $A_r(O) = 15.9994$] include: 1894, 56.04; 1896, 56.02; 1900, 56.0; 1901, 55.9; 1909, 55.85; 1912, 55.84; 1940, 55.85; and 1961, 55.847(3).

2.3. Antimony

The Commission has changed the recommended value for the standard atomic weight of antimony to $A_r(Sb) = 121.760(1)$, based on the calibrated positive thermal ionization mass-spectrometric determination by Chang *et al.*[23] The previous value of $A_r(Sb) = 121.757(3)$, which was adopted by the Commission in 1989[2] was based on the mass-spectrometric measurement by de Laeter and Hosie,[24] which was supported by other high quality measurements by Chang *et al.*,[25] and by Wachsmann and Heumann.[26] Historical values of $A_r(Sb)$ [values before 1961 are based on $A_r(O) = 16$ exactly; more recent values are concordant with $A_r(O) = 15.9994$] include: 1894, 120.23; 1896, 120.43; 1900, 120.4; 1924, 120.2; 1925, 121.77; 1961, 121.75; 1969, 121.75(3); and 1989, 121.757(3).

A survey of five stibnite minerals and five laboratory reagents was also carried out by Chang *et al.*[23] No evidence of isotopic fractionation for any of the terrestrial materials was found.

2.4. Iridium

The Commission has changed the recommended value for the standard atomic weight of iridium to $A_r(Ir) = 192.217(3)$ based on recent high precision measurements using both positive and negative thermal ionization mass spectrometry. The previous value, $A_r(Ir) = 192.22(3)$, was based on two mass-spectrometric determinations by Sampson and Bleakney[27] and Baldock.[28] A more recent $A_r(Ir)$ value reported by Creaser *et al.*[29] was not considered by the Commission due to the fact that only a single measurement was made. Recent work by Walczyk and Heumann[30] and Chang and Xiao[31] were evaluated by the Commission. The work of Walczyk and Heumann was chosen by the Commission as the best measurement due to its better precision; however, both measurements are in agreement with their stated uncertainties. The new value represents a significant improvement in the precision of the atomic weight and is in agreement with the previous measurements. Historical values of $A_r(Ir)$ [values before 1961 are based on $A_r(O) = 16$ exactly; more recent values are concordant with $A_r(O) = 15.9994$] include: 1894, 193.1; 1896, 193.12; 1900, 193.1; 1903, 193.0; 1909, 193.1; 1953, 192.2; 1969, 192.22(3).

2.5. Lithium

The Commission has noted with concern the commercial dissemination of significant quantities of laboratory reagents that have been artificially depleted in ^{6}Li, resulting in labels on containers of reagents with incorrect atomic-weight values, which actually may range from 6.94 to 6.99. To make chemists aware of this problem, the Commission has enclosed A_r(Li) in brackets in Tables 1 and 2. To emphasize that ^{6}Li depleted materials are commonly available (especially in the U.S. and Europe), the listed value is therefore marked with a dagger, and the footnote for the dagger reads:

> Commercially available Li materials have atomic weights that range between 6.94 and 6.99; if a more accurate value is required, it must be determined for the specific material.

An article discussing the variation in A_r(Li) will be prepared during 1994.

3. The Table of Standard Atomic Weights 1993

Following past practice, the Table of Standard Atomic Weights 1993 is presented both in alphabetical order by names in English of the elements (Table 1) and in the order of atomic numbers (Table 2).

The Commission wishes to emphasize the need for new precise calibrated isotopic composition measurements in order to improve the accuracy of the atomic weights of a number of elements which are still not known to a satisfactory level of accuracy.

The names and symbols for those elements with atomic numbers 104 to 109 referred to in the following tables are systematic and based on the atomic numbers of the elements recommended for temporary use by the IUPAC Commission of the Nomenclature of Inorganic Chemistry.[32] The names are composed of the following roots representing digits of the atomic number:

1 un,	2 bi,	3 tri,	4 quad,	5 pent,
6 hex,	7 sept,	8 oct,	9 enn,	0 nil.

The ending "ium" is then added to these three roots. The three-letter symbols are derived from the first letter of the corresponding roots.

4. Relative Atomic Masses and Half-lives of Selected Radionuclides

The Commission on Atomic Weights and Isotopic Abundances as in previous years publishes a table of relative atomic masses and half-lives of selected radionuclides for elements without a stable nuclide (see Table 3). Since the Commission has no prime responsibility for the dissemination of such values, it has not attempted either to record the best precision possible or to make its tabulation comprehensive. There is no general agreement on which of the isotopes of the radioactive elements is, or is likely to be judged, "important." Various criteria such as "longest half-life", "production in quantity", "used commercially", *etc.*, have been applied in the Commission's choice. The relative atomic masses are derived from the atomic masses (in u) recommended by Audi and Wapstra.[3] The half-lives listed are those provided by Holden.[33,34,35,36]

5. 1993 Table of Standard Atomic Weights Abridged to Five Significant Figures

5.1. Introduction

The detail and the number of significant figures in the IUPAC Table of Standard Atomic Weights, as found in the biennial reports of the Commission on Atomic Weights and Isotopic Abundances, published in Pure and Applied Chemistry, exceed the needs and interests of most users, who are more concerned with the length of time during which a given table has validity to the precision limit of their interests. Accordingly, the Commission on Atomic Weights and Isotopic Abundances in 1987 decided to prepare for publication a revised and updated version of the 1981 Table of Atomic Weights Abridged to Five Significant Figures, or fewer where uncertainties do not warrant even five-figure accuracy (this currently applies to eight elements). When an atomic weight is known to more than five significant figures, it is abridged in this Table to the five-figure value closest to the unabridged best value. When the sixth digit of the unabridged value is 5 exactly, it is rounded up or down to make the fifth digit in this abridged Table even. The single-digit uncertainty in the tabulated atomic weight is held to be symmetric — that is, it is applicable with either a positive or a negative sign.

The abridged Table (Table 4) is here given with the reasonable hope that not even one of the quoted values will need to be changed because of every biennial revision of the unabridged Table, although the quoted uncertainties may have altered. Moreover, any change in an abridged value will probably be by only one unit in the last significant figure or by adding a fifth significant figure where only four can be given now. Such constancy in these values is desirable for textbooks and numerical tables derived from atomic-weight data. However, it should be remembered that the best atomic-weight values of 27 elements are still uncertain by more than one unit in the fifth significant figure. The annotated warnings of anomalous geological occurrences, isotopically altered materials, and variability of radioactive elements are relevant even in the abridged Table. The footnote concerning lithium is particularly important.

6. Reporting Relative Abundance Data for Stable Hydrogen, Carbon, and Oxygen Isotopes

It has come to the attention of the Commission that relative isotopic ratio data for hydrogen, carbon, and oxygen are commonly expressed by different authors on non-corresponding scales. To eliminate possible confusion in the reporting of such isotopic abundances, the Commission recommends that:

(1) ^{2}H/^{1}H relative ratios of all substances be expressed relative to VSMOW (Vienna Standard Mean Ocean Water) on a scale such that the ^{2}H/^{1}H of SLAP (StandardLight Antarctic Precipitation) is 0.572 times that of VSMOW,

that is, the δ^2H value of SLAP is -428 per mil (‰ or parts per thousand) relative to VSMOW;

(2) $^{13}C/^{12}C$ relative ratios of all substances be expressed relative to VPDB (Vienna Peedee belemnite) on a scale such that the $^{13}C/^{12}C$ of NBS 19 carbonate is 1.00195 times that of VPDB, that is, the $\delta^{13}C$ value of NBS 19 is defined to be +1.95 per mil relative to VPDB;

(3) $^{18}O/^{16}O$ relative ratios of all substances be expressed relative to either VSMOW or VPDB on scales such that the $^{18}O/^{16}O$ of SLAP is 0.9445 times that of VSMOW, that is, the $\delta^{18}O$ value of SLAP is -55.5 per mil relative to VSMOW; and

(4) Reporting of isotopic abundances relative to SMOW (Standard Mean Ocean Water) and PDB (Peedee belemnite) be discontinued.

Furthermore, if reported isotopic abundances of a mineral or compound have been determined using isotopic fractionation factors, users should (i) indicate their values of all such isotopic fractionation factors, or (ii) indicate the isotopic abundance obtained for a reference material of the same mineral or compound. A report discussing reporting of hydrogen, carbon, and oxygen isotopic abundances has been prepared by T. B. Coplen[37].

The Commission also recommends that only International Atomic Energy Agency distributed primary stable isotopic reference materials, such as VSMOW water, SLAP water, and NBS 19 calcium carbonate, be used to calibrate local laboratory reference materials for use in determining relative stable hydrogen, carbon, and oxygen isotopic abundances.

7. Non-Terrestrial Data

The isotopic abundance of elements from non-terrestrial sources form a rapidly expanding body of knowledge. Information about non-terrestrial isotopic abundances can be obtained from mass-spectrometric studies of meteoritic, lunar or interplanetary dust materials, from space probes using mass and far-infrared to ultraviolet spectra, from ground-based astronomical photoelectric and radio observations.

It has been established that many elements can have a different isotopic composition in non-terrestrial materials from that in normal terrestrial matter. These effects have been substantiated by recent precise mass-spectrometric measurements of meteorites, lunar material, and interplanetary dust. Recently, very large variations in isotopic abundance have been reported for a wide range of elements in meteoritic materials. An example of this has been found during grain by grain isotopic analyses of the minute components of primordial meteorites, such as the SiC in the Murchison carbonaceous chondrite which shows very large variations (up to 3 orders of magnitude greater than terrestrial variation) in the carbon and nitrogen isotopic abundances (see Fig. 1 and Ref. 38) These large variations cannot be explained by any known process for terrestrial materials but agree with isotopic variations predicted by nucleosynthetic models. Clearly, the SiC from Murchison has several different nucleosynthetic origins and predates the formation of our solar system. This example shows that the early solar system was not completely homogenized with respect to the isotopic composition of the elements and that extra-solar materials still reside in our solar system.

Excellent reviews describing isotopic anomalies in non-terrestrial materials are given by Clayton,[39] Clayton *et al.*,[40] Kerridge and Matthews,[41] Ott,[42] G. J. Wasserburg,[43] Wiedenbeck,[44] and de Laeter.[45,46] Those interested in more comprehensive reviews, including specific data and additional references, should refer to Shima[47,48] and Shima and Ebihara.[49]

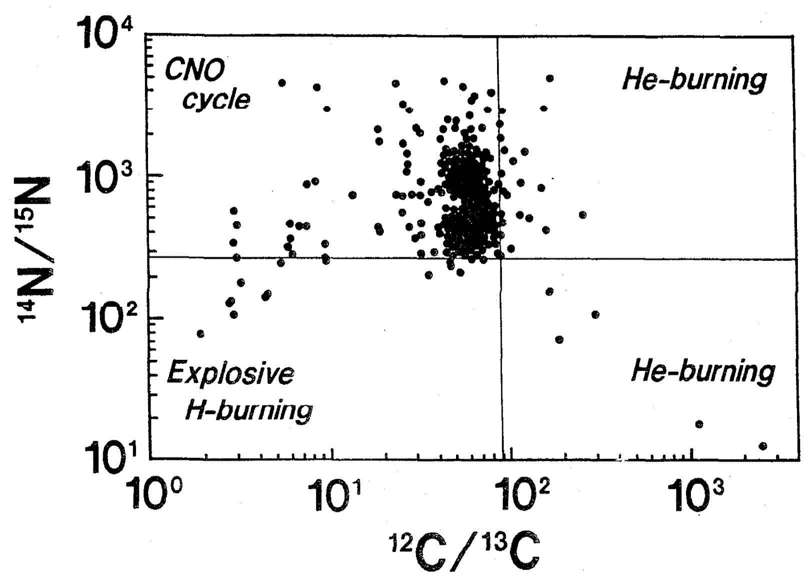

Fig. 1. The isotopic composition of nitrogen and carbon in interstellar SiC grains (average size 5μm) separated from the carbonaceous chondrite Murchison. Variations over several orders of magnitude are apparent. Most SiC grains fall into the quadrant corresponding to hydrostatic H-burning by the CNO-cycle. But a few grains are observed to fall in the other three quadrants, including that corresponding explosive H-burning. Thus, these SiC grains are expected to have been produced from different stars and during various stages of nucleosynthesis.

It is important to realize that, although most of the reported isotopic anomalies are small, some variations are quite large. For this reason, scientists dealing with the chemical analysis of non-terrestrial samples should exercise caution when the isotopic composition or the atomic weight of a non-terrestrial sample is required. The data have been classified according to major alteration or production processes, or according to sources of materials with different isotopic composition of the element. This is described in more detail in the following:

7.1. Processes

A. Mass Fractionation
Mass dependent fractionation which occurs before the formation as well as in later stages of the history of the solar system.

A–1 Fractionation by Volatilization or Condensation.

A–2 Fractionation by Chemical Processes: This includes some specific cases, such as the production of organic compounds.

B. Nuclear Reactions

B–1 Spallation Reactions: Nuclear reactions of non-terrestrial matter with energetic particles of galactic and (or) solar origin.

B–2 Low Energy Neutron Capture Reactions: Resulting from neutrons produced by spallation cascades, slowed down to lower energies in large meteorites or the moon.

C. Radioactive Decay Products

C–1 Products from Extinct Nuclides: When the solar system had evolved to the point where components of meteorites became closed isotopic systems (some 4.5 Ga ago), radioactive nuclides with suitable decay constants–now extinct in the solar system–were still present. Their subsequent decay products are responsible for anomalous isotopic compositions of certain elements.

C–2 Enrichments in decay products of radionuclides still present in the solar system. They are commonly used in geochronological and cosmochronological dating methods.

C–3 Enrichments due to double β-decay of long-lived radioactive nuclides.

C–4 Enrichments as the result of nuclear fission.

D. Nucleosynthesis
Measurements of isotopic abundances which were identified by authors as products of specific nucleosynthetic processes.

7.2. Sources

a. Interplanetary Dust (Cosmic Dust)
Isotopic ratios of certain elements have been measured in small particles collected in the Earth's stratosphere, found near polar regions or have been separated from deep sea sediments.

b. Solar Materials

b–1 Solar Wind: Ancient or recent solar wind particles are trapped in lunar samples or in some meteorites.

b–2 Solar Flares: During the solar event of Sept. 23, 1978, the spacecraft-borne Heavy Isotope Spectrometer Telescope (HIST) measured isotopic ratios of several elements of energetic particles emitted from the sun. Such particles can also be detected in meteorites.

b–3 Sun: Isotopic ratios of He and Ni were measured by ground-based infrared or near-infrared spectrometry in the solar photosphere.

c. Cosmic Rays
Data included in this category are the result of measurements in the near-Earth environment by balloon or spacecraft experiments.

c–1 Relatively Low-Energy Cosmic Rays (>20 MeV/n to 1 GeV/n; where n = nucleon): The recent developments of high resolution detectors make it possible to measure the relative isotopic abundance of several elements.

c–2 High-Energy Cosmic Rays (>6 GeV/n): Despite experimental difficulties $^3He/^4He$ ratios have been determined.

d. Planets and Satellites
Isotopic ratios of some elements in planets and in Saturn's moon, Titan, were determined by spacecraft-borne mass spectrometry and ground-based infrared spectrometry.

e. Cool Stars
The number of known isotopic ratios of H, Li, C, O, and Mg in cool giant stars has recently grown remarkably. Most of them have been obtained from infrared spectra taken with ground-based telescopes.

f. Interstellar Medium
Isotopic ratios of H, He, Li, C, N, and O have been detected by large ground-based radio telescopes and by satellite-borne ultraviolet or far-infrared spectrometry.

g. Comet Halley
D/H and $^{18}O/^{16}O$ ratios in the coma of the comet Halley were measured on March 14, 1986 by the neutral gas mass spectrometer of the Giotto spacecraft. The isotopic ratios of C and N of cometary material are determined by CN rotational lines of ultraviolet spectra.

Although this Commission does not attempt to systematically review the literature on the isotopic composition of non-terrestrial materials, some examples of isotopic variations have been given in past reports. In order to provide a more comprehensive view of recent research on the isotopic variations found in these materials, we have chosen in this report to present some of these data in Tables 5 and 6.

Table 5 lists experimental results for a selection of the largest reported variations. This information has been classified in terms of the major process involved which produces the difference in isotopic composition from the normal terrestrial isotopic composition. Thus, for example, the table lists the largest deviation reported for ^{53}Cr caused by decay of the now extinct nuclide ^{53}Mn (process C–1). Each individual process is listed only once. These data are measured values reported in publications and do not represent extrapolated individual compositions of specific processes.

Entries given as "δ" are in ‰ (parts per thousand). The "δ" values are expressed by respective numbers, *e.g.*, the meaning of δ(53,52) is as follows:

$$\delta(53,52)=\left[\frac{[^{53}Cr/^{52}Cr]\text{non-terrestrial sample}}{[^{53}Cr/^{52}Cr]\text{terrestrial standard}}-1\right]1000$$

Where an isotopic ratio or an atomic weight is given, the terrestrial value (truncated where necessary to an appropriate number of significant figures) is given for comparison in parenthesis.

Table 6 lists examples of isotopic compositions and atomic weights of elements from different non-terrestrial sources.

8. Other Projects of the Commission

The *Working Party on Natural Isotopic Fractionation* presented a report which was produced during the Working Party's meeting in Sintra, Portugal, before the IUPAC General Assembly in Lisbon and included comments from the Working Party's meeting in March 1992 at Brookhaven National Laboratory, Upton, New York. The Working Party has decided to prepare a report for *Pure & Appl. Chem*., consisting primarily of plots (where possible) that show the variation in natural isotopic abundance, atomic weights, and standard δ values (where possible) for the elements H, He, Li, B, C, N, O, Ne, Si, S, Cl, K, Fe, Cu, Se, Pd, Te, and U. A companion report that will be much longer will include numerous references to be published as a *U.S. Geological Survey Open-File Report*.

At its Brookhaven meeting the *Working Party on Natural Isotopic Fractionation* discussed the various spellings of the symbol ‰ (parts per thousand) used to express stable-isotope-ratio data. It was concluded that (i) it would be too difficult to advocate a uniform spelling for "per mil" (also per mill, per mille, permil, *etc*.), and (ii) alternative units should not be considered. These conclusions were reaffirmed in Sintra and at the Commission's meeting in Lisbon. It might be appropriate for CAWIA to seek guidance from the International Organization of Standardization.

The *Working Party on Natural Isotopic Fractionation* has noted that the uncertainties in the values of isotopic reference materials distributed by the International Atomic Energy Agency (Vienna, Austria) and the National Institute of Standards and Technology (Gaithersburg, Maryland, USA) might be improved by a detailed assessment. Thus, it was resolved that the Working Party will become involved in the evaluation of isotopic reference materials and will prepare a "Review of Isotope-Reference Materials" for IUPAC with updates every two years or as appropriate.

In 1989 it was recognized by the Commission that apart from those elements for which there is a "calibrated measurement" or which have an atomic number less than 19, uncertainties calculated using the current guidelines often significantly underestimate what is considered by the Commission to be appropriate. Therefore it seemed desirable to incorporate into these guidelines some of the other factors the Commission routinely incorporated into these calculations. Also most published data which the *Subcommittee for Isotopic Abundance Measurements* evaluates are now in the form of isotopic abundance ratios rather than isotopic abundances. Therefore, to meet these concerns, the Commission established the *Working Party on Statistical Evaluation of Isotopic Abundances* to (i) modify guidelines to take into account isotope fractionation, and (ii) develop computational procedures and computer software for computing atomic weights and uncertainties in a completely orthodox manner from either isotopic ratios or isotopic abundances, including the calculation of variance. The Working Party completed its tasks and recommended that (i) the new guidelines, as well as the new computational procedures, be used for the preparation of the "1995 Table of Isotopic Compositions of the Elements," (ii) the Commission support the publication of "Computational procedures for the calculation of the atomic weight of an element and its uncertainty from measured or published isotopic measurement data" by F. Schaefer, S. Valkiers, P. D. P. Taylor and P. De Bièvre and "Assessment procedures used to evaluate published isotopic abundance data" by K. Rosman, P. D. P. Taylor, P. De Bièvre and J. Gramlich. J. de Laeter will incorporate these guidelines into the Commission's new Technical Handbook, which he plans to complete in early 1994.

During the last two years, documents by Aston, Baxter, Soddy, Curie, Hahn, Richards, and others (dating from the earlier half of this century) were transferred from IUPAC headquarters to the *Commission's archive* at the Chemical Heritage Foundation (previously known as the Arnold and Mabel Beckman Center for the History of Chemistry) in Philadelphia by N. N. Greenwood, H. S. Peiser, T. Murphy, and T. B. Coplen. Along with N. Holden the above named individuals have provided assistance in organizing the archive during the past two years.

TABLE 1. Standard atomic weights 1993 [Scaled to $A_r(^{12}C) = 12$]. The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$

Alphabetical order in English

Name	Symbol	Atomic number	Atomic weight	Footnotes		
Actinium*	Ac	89				
Aluminium (Aluminum)	Al	13	26.981539(5)			
Americium*	Am	95				
Antimony (Stibium)	Sb	51	121.760(1)	g		
Argon	Ar	18	39.948(1)	g		r
Arsenic	As	33	74.92159(2)			

TABLE 1. Standard atomic weights 1993 [Scaled to $A_r(^{12}C) = 12$]. The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$ — Continued

Alphabetical order in English

Name	Symbol	Atomic number	Atomic weight	Footnotes		
Astatine*	At	85				
Barium	Ba	56	137.327(7)			
Berkelium*	Bk	97				
Beryllium	Be	4	9.012182(3)			
Bismuth	Bi	83	208.98037(3)			
Boron	B	5	10.811(5)	g	m	r
Bromine	Br	35	79.904(1)			
Cadmium	Cd	48	112.411(8)	g		
Caesium (Cesium)	Cs	55	132.90543(5)			
Calcium	Ca	20	40.078(4)	g		
Californium*	Cf	98				
Carbon	C	6	12.011(1)	g		r
Cerium	Ce	58	140.115(4)	g		
Chlorine	Cl	17	35.4527(9)		m	
Chromium	Cr	24	51.9961(6)			
Cobalt	Co	27	58.93320(1)			
Copper	Cu	29	63.546(3)			r
Curium*	Cm	96				
Dysprosium	Dy	66	162.50(3)	g		
Einsteinium*	Es	99				
Erbium	Er	68	167.26(3)	g		
Europium	Eu	63	151.965(9)	g		
Fermium*	Fm	100				
Fluorine	F	9	18.9984032(9)			
Francium*	Fr	87				
Gadolinium	Gd	64	157.25(3)	g		
Gallium	Ga	31	69.723(1)			
Germanium	Ge	32	72.61(2)			
Gold	Au	79	196.96654(3)			
Hafnium	Hf	72	178.49(2)			
Helium	He	2	4.002602(2)	g		r
Holmium	Ho	67	164.93032(3)			
Hydrogen	H	1	1.00794(7)	g	m	r
Indium	In	49	114.818(3)			
Iodine	I	53	126.90447(3)			
Iridium	Ir	77	192.217(3)			
Iron	Fe	26	55.845(2)			
Krypton	Kr	36	83.80(1)	g	m	
Lanthanum	La	57	138.9055(2)	g		
Lawrencium*	Lr	103				
Lead	Pb	82	207.2(1)	g		r
Lithium	Li	3	[6.941(2)]†	g	m	r
Lutetium	Lu	71	174.967(1)	g		
Magnesium	Mg	12	24.3050(6)			
Manganese	Mn	25	54.93805(1)			
Mendelevium*	Md	101				
Mercury	Hg	80	200.59(2)			
Molybdenum	Mo	42	95.94(1)	g		
Neodymium	Nd	60	144.24(3)	g		
Neon	Ne	10	20.1797(6)	g	m	
Neptunium*	Np	93				
Nickel	Ni	28	58.6934(2)			
Niobium	Nb	41	92.90638(2)			
Nitrogen	N	7	14.00674(7)	g		r
Nobelium*	No	102				
Osmium	Os	76	190.23(3)	g		
Oxygen	O	8	15.9994(3)	g		r
Palladium	Pd	46	106.42(1)	g		
Phosphorus	P	15	30.973762(4)			
Platinum	Pt	78	195.08(3)			

TABLE 1. Standard atomic weights 1993 [Scaled to $A_r(^{12}C) = 12$]. The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$ — Continued

Alphabetical order in English

Name	Symbol	Atomic number	Atomic weight	Footnotes		
Plutonium*	Pu	94				
Polonium*	Po	84				
Potassium (Kalium)	K	19	39.0983(1)	g		
Praseodymium	Pr	59	140.90765(3)			
Promethium*	Pm	61				
Protactinium*	Pa	91	231.03588(2)			
Radium*	Ra	88				
Radon*	Rn	86				
Rhenium	Re	75	186.207(1)			
Rhodium	Rh	45	102.90550(3)			
Rubidium	Rb	37	85.4678(3)	g		
Ruthenium	Ru	44	101.07(2)	g		
Samarium	Sm	62	150.36(3)	g		
Scandium	Sc	21	44.955910(9)			
Selenium	Se	34	78.96(3)			
Silicon	Si	14	28.0855(3)			r
Silver	Ag	47	107.8682(2)	g		
Sodium (Natrium)	Na	11	22.989768(6)			
Strontium	Sr	38	87.62(1)	g		r
Sulfur	S	16	32.066(6)	g		r
Tantalum	Ta	73	180.9479(1)			
Technetium*	Tc	43				
Tellurium	Te	52	127.60(3)	g		
Terbium	Tb	65	158.92534(3)			
Thallium	Tl	81	204.3833(2)			
Thorium*	Th	90	232.0381(1)	g		
Thulium	Tm	69	168.93421(3)			
Tin	Sn	50	118.710(7)	g		
Titanium	Ti	22	47.867(1)			
Tungsten (Wolfram)	W	74	183.84(1)			
Unnilennium*	Une	109				
Unnilhexium*	Unh	106				
Unniloctium*	Uno	108				
Unnilpentium*	Unp	105				
Unnilquadium*	Unq	104				
Unnilseptium*	Uns	107				
Uranium*	U	92	238.0289(1)	g	m	
Vanadium	V	23	50.9415(1)			
Xenon	Xe	54	131.29(2)	g	m	
Ytterbium	Yb	70	173.04(3)	g		
Yttrium	Y	39	88.90585(2)			
Zinc	Zn	30	65.39(2)			
Zirconium	Zr	40	91.224(2)	g		

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

†Commercially available Li materials have atomic weights that range between 6.94 and 6.99; if a more accurate value is required, it must be determined for the specific material.

[g]geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed the stated uncertainty.

[m]modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic weight of the element from that given in the Table can occur.

[r]range in isotopic composition of normal terrestrial material prevents a more precise $A_r(E)$ being given; the tabulated $A_r(E)$ value should be applicable to any normal material.

TABLE 2. Standard atomic weights 1993 [Scaled to $A_r(^{12}C) = 12$]. The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$.

Order of atomic number

Atomic number	Name	Symbol	Atomic weight	Footnotes		
1	Hydrogen	H	1.00794(7)	g	m	r
2	Helium	He	4.002602(2)	g		r
3	Lithium	Li	[6.941(2)]†	g	m	r
4	Beryllium	Be	9.012182(3)			
5	Boron	B	10.811(5)	g	m	r
6	Carbon	C	12.011(1)	g		r
7	Nitrogen	N	14.00674(7)	g		r
8	Oxygen	O	15.9994(3)	g		r
9	Fluorine	F	18.9984032(9)			
10	Neon	Ne	20.1797(6)	g	m	
11	Sodium (Natrium)	Na	22.989768(6)			
12	Magnesium	Mg	24.3050(6)			
13	Aluminium (Aluminum)	Al	26.981539(5)			
14	Silicon	Si	28.0855(3)			r
15	Phosphorus	P	30.973762(4)			
16	Sulfur	S	32.066(6)	g		r
17	Chlorine	Cl	35.4527(9)		m	
18	Argon	Ar	39.948(1)	g		r
19	Potassium (Kalium)	K	39.0983(1)	g		
20	Calcium	Ca	40.078(4)	g		
21	Scandium	Sc	44.955910(9)			
22	Titanium	Ti	47.867(1)			
23	Vanadium	V	50.9415(1)			
24	Chromium	Cr	51.9961(6)			
25	Manganese	Mn	54.93805(1)			
26	Iron	Fe	55.845(2)			
27	Cobalt	Co	58.93320(1)			
28	Nickel	Ni	58.6934(2)			
29	Copper	Cu	63.546(3)			r
30	Zinc	Zn	65.39(2)			
31	Gallium	Ga	69.723(1)			
32	Germanium	Ge	72.61(2)			
33	Arsenic	As	74.92159(2)			
34	Selenium	Se	78.96(3)			
35	Bromine	Br	79.904(1)			
36	Krypton	Kr	83.80(1)	g	m	
37	Rubidium	Rb	85.4678(3)	g		
38	Strontium	Sr	87.62(1)	g		r
39	Yttrium	Y	88.90585(2)			
40	Zirconium	Zr	91.224(2)	g		
41	Niobium	Nb	92.90638(2)			
42	Molybdenum	Mo	95.94(1)	g		
43	Technetium*	Tc				
44	Ruthenium	Ru	101.07(2)	g		
45	Rhodium	Rh	102.90550(3)			
46	Palladium	Pd	106.42(1)	g		
47	Silver	Ag	107.8682(2)	g		
48	Cadmium	Cd	112.411(8)	g		
49	Indium	In	114.818(3)			
50	Tin	Sn	118.710(7)	g		
51	Antimony (Stibium)	Sb	121.760(1)	g		
52	Tellurium	Te	127.60(3)	g		
53	Iodine	I	126.90447(3)			
54	Xenon	Xe	131.29(2)	g	m	
55	Caesium (Cesium)	Cs	132.90543(5)			
56	Barium	Ba	137.327(7)			
57	Lanthanum	La	138.9055(2)	g		
58	Cerium	Ce	140.115(4)	g		
59	Praseodymium	Pr	140.90765(3)			
60	Neodymium	Nd	144.24(3)	g		

TABLE 2. Standard atomic weights 1993 [Scaled to $A_r(^{12}C) = 12$]. The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of A_r(E) and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of A_r(E) — Continued

Order of atomic number

Atomic number	Name	Symbol	Atomic weight	Footnotes		
61	Promethium*	Pm				
62	Samarium	Sm	150.36(3)	g		
63	Europium	Eu	151.965(9)	g		
64	Gadolinium	Gd	157.25(3)	g		
65	Terbium	Tb	158.92534(3)			
66	Dysprosium	Dy	162.50(3)	g		
67	Holmium	Ho	164.93032(3)			
68	Erbium	Er	167.26(3)	g		
69	Thulium	Tm	168.93421(3)			
70	Ytterbium	Yb	173.04(3)	g		
71	Lutetium	Lu	174.967(1)	g		
72	Hafnium	Hf	178.49(2)			
73	Tantalum	Ta	180.9479(1)			
74	Tungsten (Wolfram)	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	195.08(3)			
79	Gold	Au	196.96654(3)			
80	Mercury	Hg	200.59(2)			
81	Thallium	Tl	204.3833(2)			
82	Lead	Pb	207.2(1)	g		r
83	Bismuth	Bi	208.98037(3)			
84	Polonium*	Po				
85	Astatine*	At				
86	Radon*	Rn				
87	Francium*	Fr				
88	Radium*	Ra				
89	Actinium*	Ac				
90	Thorium*	Th	232.0381(1)	g		
91	Protactinium*	Pa	231.03588(2)			
92	Uranium*	U	238.0289(1)	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	Unnilquadium*	Unq				
105	Unnilpentium*	Unp				
106	Unnilhexium*	Unh				
107	Unnilseptium*	Uns				
108	Unniloctium*	Uno				
109	Unnilennium*	Une				

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

†Commercially available Li materials have atomic weights that range between 6.94 and 6.99; if a more accurate value is required, it must be determined for the specific material.

[g]geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed the stated uncertainty.

[m]modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic weight of the element from that given in the Table can occur.

[r]range in isotopic composition of normal terrestrial material prevents a more precise A_r(E) being given; the tabulated A_r(E) value should be applicable to any normal material.

TABLE 3. Relative atomic masses and half-lives of selected radionuclides

Atomic number	Name	Symbol	Mass number	Relative atomic Mass	Half-Life	Unit[a]
43	Technetium	Tc	97	96.9064	2.6×10^6	a
			98	97.9072	4.2×10^6	a
			99	98.9063	2.1×10^5	a
61	Promethium	Pm	145	144.9127	18	a
			147	146.9151	2.62	a
84	Polonium	Po	209	208.9824	102	a
			210	209.9828	138.4	d
85	Astatine	At	210	209.9871	8	h
			211	210.9875	7.2	h
86	Radon	Rn	211	210.9906	15	h
			220	220.0114	56	s
			222	222.0176	3.823	d
87	Francium	Fr	223	223.0197	22	m
88	Radium	Ra	223	223.0185	11	d
			224	224.0202	3.7	d
			226	226.0254	1.6×10^3	a
			228	228.0311	5.75	a
89	Actinium	Ac	227	227.0278	21.77	a
90	Thorium	Th	230	230.0331	7.54×10^4	a
			232	232.0381	1.40×10^{10}	a
91	Protactinium	Pa	231	231.0359	3.25×10^4	a
92	Uranium	U	233	233.0396	1.59×10^5	a
			234	234.0409	2.46×10^5	a
			235	235.0439	7.04×10^8	a
			236	236.0456	2.34×10^7	a
			238	238.0508	4.47×10^9	a
93	Neptunium	Np	237	237.0482	2.14×10^6	a
			239	239.0529	2.35	d
94	Plutonium	Pu	238	238.0496	87.7	a
			239	239.0522	2.41×10^4	a
			240	240.0538	6.56×10^3	a
			241	241.0568	14.4	a
			242	242.0587	3.75×10^5	a
			244	244.0642	8.0×10^7	a
95	Americium	Am	241	241.0568	433	a
			243	243.0614	7.37×10^3	a
96	Curium	Cm	243	243.0614	29.1	a
			244	244.0627	18.1	a
			245	245.0655	8.5×10^3	a
			246	246.0672	4.8×10^3	a
			247	247.0703	1.6×10^7	a
			248	248.0723	3.5×10^5	a
97	Berkelium	Bk	247	247.0703	1.4×10^3	a
			249	249.0750	3.2×10^2	d
98	Californium	Cf	249	249.0748	3.5×10^2	a
			250	250.0764	13.1	a
			251	251.0796	9.0×10^2	a
			252	252.0816	2.64	a
99	Einsteinium	Es	252	252.083	1.3	a
100	Fermium	Fm	257	257.0951	101	d
101	Mendelevium	Md	256	256.094	76	m
			258	258.10	52	d
102	Nobelium	No	259	259.1009	58	m
103	Lawrencium	Lr	262	262.11	216	m
104	Unnilquadium	Unq	261	261.11	65	s
105	Unnilpentium	Unp	262	262.114	34	s
106	Unnilhexium	Unh	263	263.118	0.8	s
107	Unnilseptium	Uns	262	262.12	0.1	s
108	Unniloctium	Uno	265		0.002[b]	s
109	Unnilennium	Une	266		0.003[b]	s

[a]Abbreviations are: a = years; d = days; h = hours; m = minutes; s = seconds.
[b]The value given is determined from only a few decays.

TABLE 4. Standard atomic weights abridged to five significant figures

Atomic weights, scaled to the relative atomic mass, $A_r(^{12}C) = 12$, are here quoted to five significant figures unless the dependable accuracy is more limited by either the combined uncertainties of the best published atomic-weight determinations, or by the variability of isotopic composition in normal terrestrial occurrences (the latter applies to elements **annotated r**). The last significant figure of each tabulated value is considered reliable to ±1 except when a larger single-digit uncertainty is inserted in parentheses following the atomic weight. Neither the highest nor the lowest actual atomic weight of any normal sample is thought likely to differ from the tabulated value by more than the assigned uncertainty. However, the tabulated values do not apply either to samples of highly exceptional isotopic composition arising from most unusual geological occurrences (for elements **annotated g**) or to those whose isotopic composition has been artificially altered. Such might even be found in commerce without disclosure of that modification (for elements **annotated m**). Elements annotated by an asterisk (*) have no stable isotope and are generally represented in this Table by just one of the element's commonly known radioisotopes, with a corresponding relative atomic mass in the atomic-weight column. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated. For more detailed information users should refer to the full IUPAC Table of Standard Atomic Weights.

Name	Symbol	Atomic No.	Atomic Wt.	Annotations		
Actinium*	^{227}Ac	89	227.03			
Aluminium (Aluminum)	Al	13	26.982			
Americium*	^{241}Am	95	241.06			
Antimony (Stibium)	Sb	51	121.76	g		
Argon	Ar	18	39.948	g		r
Arsenic	As	33	74.922			
Astatine*	^{210}At	85	209.99			
Barium	Ba	56	137.33			
Berkelium*	^{249}Bk	97	249.08			
Beryllium	Be	4	9.0122			
Bismuth	Bi	83	208.98			
Boron	B	5	10.811(5)	g	m	r
Bromine	Br	35	79.904			
Cadmium	Cd	48	112.41			
Caesium (Cesium)	Cs	55	132.91			
Calcium	Ca	20	40.078(4)	g		
Californium*	^{252}Cf	98	252.08			
Carbon	C	6	12.011	g		r
Cerium	Ce	58	140.12	g		
Chlorine	Cl	17	35.453		m	
Chromium	Cr	24	51.996			
Cobalt	Co	27	58.933			
Copper	Cu	29	63.546(3)			r
Curium*	^{244}Cm	96	244.06			
Dysprosium	Dy	66	162.50(3)	g		
Einsteinium*	^{252}Es	99	252.08			
Erbium	Er	68	167.26(3)	g		
Europium	Eu	63	151.96	g		
Fermium*	^{257}Fm	100	257.10			
Fluorine	F	9	18.998			
Francium*	^{223}Fr	87	223.02			
Gadolinium	Gd	64	157.25(3)	g		
Gallium	Ga	31	69.723			
Germanium	Ge	32	72.61(2)			
Gold	Au	79	196.97			
Hafnium	Hf	72	178.49(2)			
Helium	He	2	4.0026			
Holmium	Ho	67	164.93			
Hydrogen	H	1	1.0079	g	m	
Indium	In	49	114.82			
Iodine	I	53	126.90			
Iridium	Ir	77	192.22			
Iron	Fe	26	55.845(2)			
Krypton	Kr	36	83.80	g	m	
Lanthanum	La	57	138.91			
Lawrencium*	^{262}Lr	103	262.11			
Lead	Pb	82	207.2	g		r
Lithium	Li	3	[6.941(2)]†	g	m	r
Lutetium	Lu	71	174.97	g		
Magnesium	Mg	12	24.305			
Manganese	Mn	25	54.938			
Mendelevium*	^{258}Md	101	258.10			

TABLE 4. Standard atomic weights abridged to five significant figures — Continued

Atomic weights, scaled to the relative atomic mass, $A_r(^{12}C) = 12$, are here quoted to five significant figures unless the dependable accuracy is more limited by either the combined uncertainties of the best published atomic-weight determinations, or by the variability of isotopic composition in normal terrestrial occurrences (the latter applies to elements **annotated r**). The last significant figure of each tabulated value is considered reliable to ±1 except when a larger single-digit uncertainty is inserted in parentheses following the atomic weight. Neither the highest nor the lowest actual atomic weight of any normal sample is thought likely to differ from the tabulated value by more than the assigned uncertainty. However, the tabulated values do not apply either to samples of highly exceptional isotopic composition arising from most unusual geological occurrences (for elements **annotated g**) or to those whose isotopic composition has been artificially altered. Such might even be found in commerce without disclosure of that modification (for elements **annotated m**). Elements annotated by an asterisk (*) have no stable isotope and are generally represented in this Table by just one of the element's commonly known radioisotopes, with a corresponding relative atomic mass in the atomic-weight column. However, three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated. For more detailed information users should refer to the full IUPAC Table of Standard Atomic Weights.

Name	Symbol	Atomic No.	Atomic Wt.	Annotations		
Mercury	Hg	80	200.59(2)			
Molybdenum	Mo	42	95.94	g		
Neodymium	Nd	60	144.24(3)	g		
Neon	Ne	10	20.180		m	
Neptunium*	^{237}Np	93	237.05			
Nickel	Ni	28	58.693			
Niobium	Nb	41	92.906			
Nitrogen	N	7	14.007			
Nobelium*	^{259}No	102	259.10			
Osmium	Os	76	190.23(3)	g		
Oxygen	O	8	15.999			
Palladium	Pd	46	106.42	g		
Phosphorus	P	15	30.974			
Platinum	Pt	78	195.08(3)			
Plutonium*	^{239}Pu	94	239.05			
Polonium*	^{210}Po	84	209.98			
Potassium (Kalium)	K	19	39.098	g		
Praseodymium	Pr	59	140.91			
Promethium*	^{147}Pm	61	146.92			
Protactinium*	Pa	91	231.04			
Radium*	^{226}Ra	88	226.03			
Radon*	^{222}Rn	86	222.02			
Rhenium	Re	75	186.21			
Rhodium	Rh	45	102.91			
Rubidium	Rb	37	85.468			
Ruthenium	Ru	44	101.07(2)	g		
Samarium	Sm	62	150.36(3)	g		
Scandium	Sc	21	44.956			
Selenium	Se	34	78.96(3)			
Silicon	Si	14	28.086			
Silver	Ag	47	107.87			
Sodium (Natrium)	Na	11	22.990			
Strontium	Sr	38	87.62	g		r
Sulfur	S	16	32.066(6)	g		r
Tantalum	Ta	73	180.95			
Technetium*	^{99}Tc	43	98.906			
Tellurium	Te	52	127.60(3)	g		
Terbium	Tb	65	158.93			
Thallium	Tl	81	204.38			
Thorium*	Th	90	232.04	g		
Thulium	Tm	69	168.93			
Tin	Sn	50	118.71			
Titanium	Ti	22	47.867			
Tungsten (Wolfram)	W	74	183.84			
Uranium*	U	92	238.03	g	m	
Vanadium	V	23	50.942			
Xenon	Xe	54	131.29(2)	g	m	
Ytterbium	Yb	70	173.04(3)	g		
Yttrium	Y	39	88.906			
Zinc	Zn	30	65.39(2)			
Zirconium	Zr	40	91.224(2)	g		

†Commercially available Li materials have atomic weights that range between 6.94 and 6.99; if a more accurate value is required, it must be determined for the specific material.

TABLE 5. Examples of observed maximum isotopic variation and corresponding atomic weights in non-terrestrial materials due to different processes

[Terrestrial isotopic abundances and atomic weights given in parentheses; δ values given in ‰ (parts per thousand).]

Element	Maximum isotopic ratios	Atomic weight	Materials	Process	Refs
$_{1}$H	δ(2,1) = +5740	1.0088	H_2O released from Semarkona (LL3-chondrite)	A–2	48
	δ(2,1) = −558	1.0079	H_2 released from Abee (E4-chondrite)	A–2	49
		(1.0079)			
$_{2}$He	$^{3}He/^{4}He = 1.42\times10^{-4}$	4.00246	Planetary type He in C-chondrites	A–1	50
	(1.37×10^{-6})	(4.00260)			
$_{10}$Ne	20 / 21 / 22				
	0.97 1 1.19	21.06	chondrite Kokubunji (L6-chondrite)	B–1	51
	(335.1 1 34.26)	(20.1797)			
$_{24}$Cr	δ(53,52) = 2600		ZnS from Qingzhen (E3-chondrite)	C–1	52
$_{36}$Kr	78 / 80 / 82 / 83 / 84 / 86				
	0.0076 3.30 1.41 0.194 1 0.317	81.41	850°C release from Allende (C3-chondrite)	B–2	53
	——— 0.355 ——— ——— 1 ———		1000°C release from FeS, Cape York (iron meteorite)	C–3	54
	(0.0061 0.039 0.203 0.202 1 0.304)	(83.80)			
$_{54}$Xe	$^{136}Xe/^{132}Xe = 0.617$		Density separate of Allende (C3-chondrite)	C–4	55
	(0.331)				
$_{62}$Sm	147 / 148 / 149 / 150 / 152				
	1.48 4.53 1 3.04 3.31		SiC from Murchison (C2-chondrite)	D	56
	(1.09 0.819 1 0.536 1.93)				
$_{76}$Os	187/188				
	0.209		Ivory Coast tektite 8902	C–2	57
	(0.120)				

TABLE 6. Examples of isotopic compositions and corresponding atomic weights in different extraterrestrial sources

Element	Source	Isotopic ratios or abundances			Atomic weight	Sample or method	Refs
$_2$He		^{3}He/^{4}He					
	Interplanetary Dust (a)	0.034			3.97	Deep Pacific magnetic fines	60
	Solar Wind (b–1)	4.88×10^{-4}			4.0021	ISEE-borne[a] IMS[b]	61
	Solar Flare (b–2)	4.1×10^{-4}			4.0022	Solar type gas-rich meteorite	62 & 63
	Sun (Photosphere) (b–3)	0.05			3.96	Infrared absorption lines	64
	Cosmic Rays (c–1) (48–77 MeV/n)[d]	0.066			3.94	ISEE-3-borne[a] HIST[c]	65
	Cosmic Rays (c–2) (about 6 GeV/n)[d]	0.24			3.8	Balloon-borne detector	66
	Interstellar Medium (f)	0.4 to 7.4×10^{-4}			4.0	Ground-based radio observation	67
	Earth (air)	1.37×10^{-6}			4.0026		
$_7$N		^{14}N/^{15}N					
	Solar Wind (b–1)	235.3			14.007	Lunar soil (released at 600°C)	68
		376.7			14.006	Lunar soil (released at 1050°C)	69
	Solar Flare (b–2)	~100			14.0	ISSE-3-born[a] HIST[c]	70
	Cosmic Ray (c–1)	0.85±0.04			14.54	Balloon-born detector	71
	Mars (d)	168±7			14.01	Viking 1,2	72
	Circumstellar Envelopes of Carbon Stars (f)						
	CRL2688	425			14.01	Ground-based telescope	73
	IRC+10216	5300			14.00	(HCN and MCCCN band)	
	Interstellar Medium (f)						
	Inner Galaxy	500			14.01	radio frequency –86 GHz	74
	Outer Galaxy	300			14.01	($CH^{12}C^{15}N/H^{13}C^{14}N$)	
	Comet Halley (g)	>200					75
	Earth (air)	272			14.0067		
$_{12}$Mg		24 /	25 /	26			
	Solar Flares (b–2)	0.772	0.114	0.114	24.327	ISEE-3-borne[a] HIST[c]	70
	Cosmic Rays (c–1) (30–180 MeV/n)[d]	0.60	0.19	0.21	24.59	ISEE-3-borne[a] HIST[c]	76
	Stars (e), (Spectr. type G, K, M)	0.79– 0.88	0.10– 0.03	0.11– 0.03	24.3– 24.0	Ground-based telescope (MgH lines)	77, 78 &79
	Earth	0.790	0.100	0.110	24.3050		

[a]High energy particle detector on board a spacecraft
[b]Ion mass spectrometer
[c]California Institute of Technology Heavy Isotope Spectrometer Telescope
[d]n = nucleon

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