# Isotopic Compositions of the Elements, 2001

**J. K. Böhlke**[a)]
*United States Geological Survey, 431 National Center, Reston, Virginia 20192*

**J. R. de Laeter**
*Department of Applied Physics, Curtin University of Technology, Perth 6001, Australia*

**P. De Bièvre**
*Independent Consultant on Metrology in Chemistry, B-2460 Kasterlee, Belgium*

**H. Hidaka**
*Department of Earth and Planetary Systems Science, Hiroshima University, Higashi-Hiroshima 739-8526, Japan*

**H. S. Peiser**[b)]
*United States Geological Survey, 431 National Center, Reston, Virginia*

**K. J. R. Rosman**
*Department of Applied Physics, Curtin University of Technology, Perth 6001, Australia*

**P. D. P. Taylor**
*Institute for Reference Materials and Measurements, European Commission, JRC, B-2440 Geel, Belgium*

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The Commission on Atomic Weights and Isotopic Abundances of the International Union of Pure and Applied Chemistry completed its last review of the isotopic compositions of the elements as determined by isotope-ratio mass spectrometry in 2001. That review involved a critical evaluation of the published literature, element by element, and forms the basis of the table of the isotopic compositions of the elements (TICE) presented here. For each element, TICE includes evaluated data from the ‘‘best measurement’’ of the isotope abundances in a single sample, along with a set of representative isotope abundances and uncertainties that accommodate known variations in normal terrestrial materials. The representative isotope abundances and uncertainties generally are consistent with the standard atomic weight of the element $A_r(E)$ and its uncertainty $U[A_r(E)]$ recommended by CAWIA in 2001. 
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Key words: atomic weight; critical evaluation; elements; isotope abundance; isotopic composition.

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## 1. Introduction

The Commission on Atomic Weights and Isotopic Abundances (CAWIA) of the International Union of Pure and Ap-

a)Author to whom correspondence should be addressed; electronic mail: jkbohlke@usgs.gov
b)This article is dedicated by the authors to the memory of H. Steffen Peiser in recognition of his immense contributions to the development of atomic weights and his outstanding service to the Commission on Atomic Weights and Isotopic Abundances. Steffen's commitment to science and his legacy of research publications have guided much of our current understanding of atomic weights, isotope abundances, and their uncertainties.

plied Chemistry (IUPAC) has provided regular assessments of the standard atomic weights and isotopic compositions of the elements.[1] CAWIA has evaluated the isotopic composition of each element (1) by examining carefully the most accurate and precise isotope-abundance measurements of the element in selected samples through its Subcommittee for Isotopic Abundance Measurements (SIAM), and (2) by compiling evidence for known variations in the isotope abundances of the element in normal terrestrial materials, recently through its Subcommittee on Natural Isotopic Fractionation (SNIF). The results of these investigations are important for a number of reasons, including: (1) the evaluated best measurements indicate the state of the metrology of isotope-abundance measurements; (2) the best measurements provide benchmark data for isotopic reference materials; and (3) the combination of best measurements and documented variations serve as the basis for the determination of the standard atomic weights of the elements. Entries in the current table of the standard atomic weights of the elements[2] are based on the atomic masses of the nuclides[3] and the isotopic compositions of the elements as evaluated by CAWIA in 2001. This paper presents the table of the isotopic compositions of the elements as evaluated by SIAM and SNIF during meetings in Maroochydore, Australia just prior to meeting of CAWIA at the 41st IUPAC General Assembly held in Brisbane, Australia in 2001. A slightly different version of this table was included in a comprehensive review of the atomic weights of the elements during the 20th century.[1] The previous table of the isotopic compositions of the elements was published in 1998,[4] following CAWIA deliberations in 1997.

At the time of the 2001 meeting, upon which this report is based, the membership of CAWIA was: *Chairman* L. Schultz (Germany); *Secretary* R. D. Loss (Australia); *Titular Members* J. K. Böhlke (USA), T. Ding (China), M. Ebihara (Japan), G. I. Ramendik (Russia), P. D. P. Taylor (Belgium); *Asociate Members* M. J. Berglund (Belgium), C. A. M. Brenninkmeijer (Germany), H. Hidaka (Japan), D. J. Rokop (USA), T. Walczyk (Switzerland), S. Yoneda (Japan); *National Representatives* P. De Bièvre (Belgium), J. R. de Laeter (Australia), C. L. do Logo (Brazil), Y. Xiao (China).

The membership of SIAM was: *Chairman* P. D. P Taylor; *Secretary* R. D. Loss (Australia); *Members* M. J. Berglund (Belgium), P. De Bièvre (Belgium), J. R. de Laeter (Australia), K. G. Heumann (Germany), H. S. Peiser (USA), D. J. Rokop (USA), K. J. R. Rosman (Australia), M. Shima (Japan), T. Walczyk (Switzerland), Y. Xiao (China).

The membership of SNIF was: *Chairman* T. B. Coplen; *Members* J. K. Böhlke (USA), C. A. M. Brenninkmeijer (Germany), P. De Bièvre (Belgium), T. Ding (China), K. G. Heumann (Germany), N. E. Holden (USA), H. R. Krouse (Canada), H. S. Peiser (USA), G. I. Ramendik (Russia), E. Roth (France).

## 2. Table of the Isotopic Compositions of the Elements

The table of the isotopic compositions of the elements was produced by CAWIA to accompany its table of standard atomic weights of the elements,[2] based on data evaluated by CAWIA in 2001. The table is intended to include data for normal terrestrial materials and does not include published values for meteoritic or other extra-terrestrial materials. Additional supporting data and background information can be found in de Laeter *et al.*[1] and Coplen *et al.*[5,6] The table consists of nine columns, as follows:

Column 1: The elements are tabulated in ascending order of atomic number ($Z$).

Column 2: The symbols for the elements ($E$) are listed using the abbreviations recommended by IUPAC.

Column 3: The mass number for each stable or quasi-stable isotope is listed.

Column 4: Range of natural variations.
No data are given in this column unless a range has been reliably established (see, for example, Coplen *et al.*[6]). The limits given may not include those of certain exceptional samples, which are indicated with a "g" in Column 5.

Column 5: Explanation of the annotations
"g" geologically exceptional specimens are known in which the element has an isotopic composition outside the reported range (refers to column 4).
"m" modified isotopic compositions may be found in commercially available material that has been subjected to an undisclosed or inadvertent isotope fractionation.
Substantial deviations from the listed isotopic compositions can occur (refers to column 9)
"r" range in isotopic composition proven to exist in normal terrestrial material limits the precision of the isotope abundances that can be given for the element (refers to column 9)

Column 6: The best measurement from a single terrestrial source.
The values are reproduced from the original literature. The uncertainties on the last digits are given in parentheses as reported in the original publication. As they are not reported in any uniform manner in the literature, "1s," "2s," or "3s" indicates 1, 2, or 3 standard deviations, "P" indicates some other "uncertainty" as defined by the author, and "se" indicates standard error (standard deviation of the mean). Where data are published as isotope-abundance ratios, the ratios and their uncertainties are converted to mole fractions using orthodox procedures.[7]

"C" is appended when calibrated mixtures have been used to correct the measurement procedure for bias, giving an "absolute" result within the "uncertainty" stated in the original publication.

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

"L" is appended when the linearity of the mass spectrometer has been established for the relevant abundance ratios by using synthetic mixtures of isotopes or certified reference materials.

"N" is appended when none of the above requirements are met.

Users should be aware of the following:

(a) A "best measurement" is not necessarily free of systematic errors, nor is it necessarily calibrated; it is just the "best" available.

(b) If a range of isotope-abundance ratios has been established for an element, the sample used for the "best measurement" may represent any part of the range.

(c) Because the data are reproduced from the literature, the sum of the isotope abundances may not equal 100%.

Column 7: Reference for the best measurement in column 6.

Column 8: Listed are the isotopic reference materials that were used for the best measurements given in column 6 (with asterisk) and agencies that distribute additional isotopic reference materials (see Sec. 3). If no asterisk is given, the best measurement was made on a substance that was not a recognized reference material.

Column 9: Representative Isotopic Composition.

In this column are listed the values that, in the opinion of CAWIA, represent the isotopic composition of chemicals and/or natural materials that are likely to be encountered in the laboratory. These values generally are consistent with the standard atomic weights;[2] however, for elements with known isotope-abundance variations, they may not necessarily correspond to the best measurements. The expanded uncertainties listed in parentheses include the range of probable isotope-abundance variations among different materials as well as experimental errors, which are derived by applying statistical guidelines used by CAWIA for assigning expanded uncertainties to published isotope-abundance measurements.

Users should be aware of the following:

(a) Values in column 9 can be used to determine the average properties of the element in materials of unspecified natural terrestrial origin, but those values may not represent the most abundant materials and it is possible that no real sample exists having the exact values listed.

(b) When precise work is to be undertaken, such as assessment of isotope-dependent properties, samples with precisely known isotopic compositions (such as those listed in column 8) should be used or suitable isotope measurements should be made.

## 3. Sources of Isotopic Reference Materials

IAEA: Reference and intercomparison samples such as VSMOW, SLAP, GISP, LSVEC, NSVEC, NBS18 and NBS19 may be purchased from:
International Atomic Energy Agency
Section of Isotope Hydrology
P.O. Box 100
1400 Vienna
Austria

NIST: NIST Standard Reference Materials (SRMs) may be purchased from:
Standard Reference Material Program
National Institute of Standards and Technology
Gaithersburg, Maryland 20899
United States of America

IRMM: Reference Materials may be obtained from:
Institute for Reference Measurements and Materials
Isotope Measurements Unit
European Commission-JRC
B-2440 Geel
Belgium

CEA: CEA distributes stable isotopes through its daughter company:
EUROISA-TOP
Parc des Algorithmes (Bat. Homère)
F-91190 St Aubin
France
For nuclear reference materials, see also:
CETAMA
CEA/DCC
Center d'Etudes Nucléaires de Fontenay aux Roses, BP-6
F 92265 Fontenay aux Roses
France

NBL: Reference materials may be obtained from:
U.S. Department of Energy
New Brunswick Laboratory
9800 S. Cass Ave.
Argonne, Illinois 60439
United States of America

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TABLE 1. Isotopic compositions of the elements, 2001

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | H | 1 | 0.999 816–0.999 974 | m,r | 0.999 844 26(5) 2s C | 8 | VSMOW* | 0.999 885(70) |
| | | 2 | 0.000 026–0.000 184 | | 0.000 155 74(5) | | CEA | 0.000 115(70)[b] |
| | | | | | | | IAEA | |
| | | | | | | | NIST | |
| 2 | He | 3 | $4.6\times10^{-10}$–0.000 041 | g,r | 0.000 001 343(13) 1s C | 9 | Air* | 0.000 001 34(3) |
| | | 4 | 0.999 959–1 | | 0.999 998 657(13) | | | 0.999 998 66(3) |
| | | | | | | | | (in air) |
| 3 | Li | 6 | 0.077 14–0.072 25 | m,r | 0.075 89(24) 2s C | 10 | IRMM-016* | [0.0759(4)][c] |
| | | 7 | 0.922 75–0.927 86 | | 0.924 11(24) | | IAEA | [0.9241(4)] |
| | | | | | | | NIST | |
| 4 | Be | 9 | | | 1.0000 | 11 | | 1.0000 |
| 5 | B | 10 | 0.189 29–0.203 86 | m,r | 0.1982(2) 2s C | 12 | IRMM-011* | 0.199(7) |
| | | 11 | 0.796 14–0.810 71 | | 0.8018(2) | | NIST | 0.801(7) |
| 6 | C | 12 | 0.988 53–0.990 37 | r | 0.988 922(28) P C | 13 | NBS19* | 0.9893(8) |
| | | 13 | 0.009 63–0.011 47 | | 0.011 078(28) | | IAEA | 0.0107(8) |
| | | | | | | | NIST | |
| 7 | N | 14 | 0.995 79–0.996 54 | r | 0.996 337(4)[d] P C | 14 | Air* | 0.996 36(20) |
| | | 15 | 0.003 46–0.004 21 | | 0.003 663(4)[d] | | IAEA | 0.003 64(20) |
| | | | | | | | NIST | |
| 8 | O | 16 | 0.997 38–0.997 76 | r | 0.997 6206(5)[e] 1s N | 15, 16 | VSMOW* | 0.997 57(16) |
| | | 17 | 0.000 37–0.000 40 | | 0.000 3790(9)[e] | | IAEA | 0.000 38(1) |
| | | 18 | 0.001 88–0.002 22 | | 0.002 0004(5)[e] | | NIST | 0.002 05(14) |
| 9 | F | 19 | | | 1.0000 | 17 | | 1.0000 |
| 10 | Ne | 20 | 0.8847–0.9051 | g,m,r | 0.904 838(90) 1s C | 18 | Air* | 0.9048(3) |
| | | 21 | 0.0027–0.0171 | | 0.002 696(5) | | | 0.0027(1) |
| | | 22 | 0.0920–0.0996 | | 0.092 465(90) | | | 0.0925(3) |
| | | | | | | | | (in air) |
| 11 | Na | 23 | | | 1.0000 | 19 | | 1.0000 |
| 12 | Mg | 24 | 0.789 58–0.790 17 | | 0.789 92(25) 2s C | 20 | NIST- | 0.7899(4) |
| | | 25 | 0.099 96–0.100 12 | | 0.100 03(9) | | SRM980* | 0.1000(1) |
| | | 26 | 0.109 87–0.110 30 | | 0.110 05(19) | | | 0.1101(3) |
| 13 | Al | 27 | | | 1.0000 | 19 | | 1.0000 |
| 14 | Si | 28 | 0.922 05–0.92241 | r | 0.922 2968(44) 2s C | 21 | IAEA | 0.922 23(19) |
| | | 29 | 0.046 78–0.046 92 | | 0.046 8316(32) | | IRMM | 0.046 85(8) |
| | | 30 | 0.030 82–0.031 02 | | 0.030 8716(32) | | NIST | 0.030 92(11) |
| 15 | P | 31 | | | 1.0000 | 11 | | 1.0000 |
| 16 | S | 32 | 0.944 54–0.952 81 | r | 0.950 4074(88) 2s C | 22 | IAEA-S1* | 0.9499(26) |
| | | 33 | 0.007 30–0.007 93 | | 0.007 4869(60) | | CEA | 0.0075(2) |
| | | 34 | 0.039 76–0.047 34 | | 0.041 9599(66) | | IAEA | 0.0425(24) |
| | | 36 | 0.000 13–0.000 19 | | 0.000 145 79(89) | | NIST | 0.0001(1) |
| 17 | Cl | 35 | 0.756 44–0.759 23 | g,m | 0.757 71(45) 2s C | 23 | NIST- | 0.7576(10) |
| | | 37 | 0.240 77–0.243 56 | | 0.242 29(45) | | SRM975* | 0.2424(10) |
| 18 | Ar | 36 | | g | 0.003 365(6) P C | 24 | Air* | 0.003 365(30) |
| | | 38 | | | 0.000 632(1) | | | 0.000 632(5) |
| | | 40 | | | 0.996 003(6) | | | 0.996 003(30) |
| | | | | | | | | (in air) |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 19 | K | 39 | | | 0.932 5811(292) 2s C | 25 | NIST- | 0.932 581(44) |
| | | 40 | | | 0.000 116 72(41) | | SRM985* | 0.000 117(1) |
| | | 41 | | | 0.067 3022(292) | | | 0.067 302(44) |
| 20 | Ca | 40 | 0.969 33–0.969 47 | g,r | 0.969 41(6) 2s N | 26 | NIST- | 0.969 41(156)[g] |
| | | 42 | 0.006 46–0.006 48 | | 0.006 47(3) | | SRM915* | 0.006 47(23) |
| | | 43 | 0.001 35–0.001 35 | | 0.001 35(2) | | | 0.001 35(10) |
| | | 44 | 0.020 82–0.020 92 | | 0.020 86(4) | | | 0.020 86(110) |
| | | 46 | 0.000 04–0.000 04 | | 0.000 04(1) | | | 0.000 04(3) |
| | | 48 | 0.001 86–0.001 88 | | 0.001 87(1) | | | 0.001 87(21) |
| 21 | Sc | 45 | | | 1.0000 | 27 | | 1.0000 |
| 22 | Ti | 46 | | | 0.082 49(21) 2s C | 28 | | 0.0825(3) |
| | | 47 | | | 0.074 37(14) | | | 0.0744(2) |
| | | 48 | | | 0.737 20(22) | | | 0.7372(3) |
| | | 49 | | | 0.054 09(10) | | | 0.0541(2) |
| | | 50 | | | 0.051 85(13) | | | 0.0518(2) |
| 23 | V | 50 | 0.002 487–0.002 502 | g | 0.002 497(6) 1s F | 29 | | 0.002 50(4) |
| | | 51 | 0.997 498–0.997 513 | | 0.997 503(6) | | | 0.997 50(4) |
| 24 | Cr | 50 | 0.042 94–0.043 45 | | 0.043 452(85) 2s C | 30 | NIST- | 0.043 45(13) |
| | | 52 | 0.837 62–0.837 90 | | 0.837 895(117) | | SRM979* | 0.837 89(18) |
| | | 53 | 0.095 01–0.095 53 | | 0.095 006(110) | | | 0.095 01(17) |
| | | 54 | 0.023 65–0.023 91 | | 0.023 647(48) | | | 0.023 65(7) |
| 25 | Mn | 55 | | | 1.0000 | 11 | | 1.0000 |
| 26 | Fe | 54 | 0.058 37–0.058 61 | | 0.058 45(23) 2s C | 31 | IRMM-014* | 0.058 45(35) |
| | | 56 | 0.917 42–0.917 60 | | 0.917 54(24) | | | 0.917 54(36) |
| | | 57 | 0.021 16–0.021 21 | | 0.021 191(65) | | | 0.021 19(10) |
| | | 58 | 0.002 81–0.002 82 | | 0.002 819(27) | | | 0.002 82(4) |
| 27 | Co | 59 | | | 1.0000 | 11 | | 1.0000 |
| 28 | Ni | 58 | | | 0.680 769(59) 2s C | 32 | NIST- | 0.680 769(89) |
| | | 60 | | | 0.262 231(51) | | SRM986* | 0.262 231(77) |
| | | 61 | | | 0.011 399(4) | | | 0.011 399(6) |
| | | 62 | | | 0.036 345(11) | | | 0.036 345(17) |
| | | 64 | | | 0.009 256(6) | | | 0.009 256(9) |
| 29 | Cu | 63 | 0.689 83–0.693 38 | r | 0.691 74(20) 2s C | 33 | NIST- | 0.6915(15) |
| | | 65 | 0.306 62–0.310 17 | | 0.308 26(20) | | SRM976* | 0.3085(15) |
| 30 | Zn | 64 | | | 0.482 68(214) 2s C | 34 | | 0.482 68(321) |
| | | 66 | | | 0.279 75(51) | | | 0.279 75(77) |
| | | 67 | | | 0.041 02(14) | | | 0.041 02(21) |
| | | 68 | | | 0.190 24(82) | | | 0.190 24(123) |
| | | 70 | | | 0.006 31(6) | | | 0.006 31(9) |
| 31 | Ga | 69 | | m | 0.601 079(62) 2s C | 35 | NIST- | 0.601 08(9) |
| | | 71 | | | 0.398 921(62) | | SRM994* | 0.398 92(9) |
| 32 | Ge | 70 | | | 0.203 75(77) 2s C | 36 | | 0.2038(18) |
| | | 72 | | | 0.273 11(103) | | | 0.2731(26) |
| | | 73 | | | 0.077 56(46) | | | 0.0776(8) |
| | | 74 | | | 0.367 29(85) | | | 0.3672(15) |
| | | 76 | | | 0.078 30(43) | | | 0.0783(7) |
| 33 | As | 75 | | | 1.0000 | 11 | | 1.0000 |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 34 | Se | 74 | | r | 0.008 89(3) 1s N | 37 | | 0.0089(4) |
| | | 76 | | | 0.093 66(18) | | | 0.0937(29) |
| | | 77 | | | 0.076 35(10) | | | 0.0763(16) |
| | | 78 | | | 0.237 72(20) | | | 0.2377(28) |
| | | 80 | | | 0.496 07(17) | | | 0.4961(41) |
| | | 82 | | | 0.087 31(10) | | | 0.0873(22) |
| 35 | Br | 79 | | | 0.506 86(26) 2s C | 38 | NIST- | 0.5069(7) |
| | | 81 | | | 0.493 14(26) | | SRM977* | 0.4931(7) |
| 36 | Kr | 78 | | g,m | 0.003 5518(32) 2s C | 39 | | 0.003 55(3) |
| | | 80 | | | 0.022 8560(96) | | | 0.022 86(10) |
| | | 82 | | | 0.115 930(62) | | | 0.115 93(31) |
| | | 83 | | | 0.114 996(58) | | | 0.115 00(19) |
| | | 84 | | | 0.569 877(58) | | | 0.569 87(15) |
| | | 86 | | | 0.172 790(32) | | | 0.172 79(41) |
| | | | | | | | | (in air) |
| 37 | Rb | 85 | | g | 0.721 654(132) 2s C | 40 | NIST- | 0.7217(2) |
| | | 87 | | | 0.278 346(132) | | SRM987* | 0.2783(2) |
| 38 | Sr | 84 | 0.0055–0.0058 | g,r | 0.005 574(16) 2s C | 41 | NIST- | 0.0056(1) |
| | | 86 | 0.0975–0.0999 | | 0.098 566(34) | | SRM987* | 0.0986(1) |
| | | 87 | 0.0694–0.0714 | | 0.070 015(26) | | NIST | 0.0700(1)[g] |
| | | 88 | 0.8229–0.8275 | | 0.825 845(66) | | | 0.8258(1) |
| 39 | Y | 89 | | | 1.0000 | 42 | | 1.0000 |
| 40 | Zr | 90 | | g | 0.514 52(9) 2s N | 43 | | 0.5145(40) |
| | | 91 | | | 0.112 23(12) | | | 0.1122(5) |
| | | 92 | | | 0.171 46(7) | | | 0.1715(8) |
| | | 94 | | | 0.1738(12) | | | 0.1738(28) |
| | | 96 | | | 0.027 99(5) | | | 0.0280(9) |
| 41 | Nb | 93 | | | 1.0000 | 19 | | 1.0000 |
| 42 | Mo | 92 | | g | 0.147 69(1) 2s L | 44 | | 0.1477(31) |
| | | 94 | | | 0.092 28(1) | | | 0.0923(10) |
| | | 95 | | | 0.159 022(4) | | | 0.1590(9) |
| | | 96 | | | 0.166 76(7) | | | 0.1668(1) |
| | | 97 | | | 0.095 618(7) | | | 0.0956(5) |
| | | 98 | | | 0.241 959(6) | | | 0.2419(26) |
| | | 100 | | | 0.096 671(4) | | | 0.0967(20) |
| 43 | Tc | | | | — | | | — |
| 44 | Ru | 96 | | g | 0.055 420(1) 1s N | 45 | | 0.0554(14) |
| | | 98 | | | 0.018 688(2) | | | 0.0187(3) |
| | | 99 | | | 0.127 579(6) | | | 0.1276(14) |
| | | 100 | | | 0.125 985(4) | | | 0.1260(7) |
| | | 101 | | | 0.170 600(10) | | | 0.1706(2) |
| | | 102 | | | 0.315 519(11) | | | 0.3155(14) |
| | | 104 | | | 0.186 210(11) | | | 0.1862(27) |
| 45 | Rh | 103 | | | 1.0000 | 11 | | 1.0000 |
| 46 | Pd | 102 | | g | 0.010 20(8) 2s C | 46 | | 0.0102(1) |
| | | 104 | | | 0.1114(5) | | | 0.1114(8) |
| | | 105 | | | 0.2233(5) | | | 0.2233(8) |
| | | 106 | | | 0.2733(2) | | | 0.2733(3) |
| | | 108 | | | 0.2646(6) | | | 0.2646(9) |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | | 110 | | | 0.1172(6) | | | 0.1172(9) |
| 47 | Ag | 107 | | g | 0.518 392(51) 2s C | 47 | NIST-SRM978* | 0.518 39(8) |
| | | 109 | | | 0.481 608(51) | | | 0.481 61(8) |
| 48 | Cd | 106 | | g | 0.0125(2) 2s F | 48 | | 0.0125(6) |
| | | 108 | | | 0.0089(1) | | | 0.0089(3) |
| | | 110 | | | 0.1249(6) | | | 0.1249(18) |
| | | 111 | | | 0.1280(4) | | | 0.1280(12) |
| | | 112 | | | 0.2413(7) | | | 0.2413(21) |
| | | 113 | | | 0.1222(4) | | | 0.1222(12) |
| | | 114 | | | 0.2873(14) | | | 0.2873(42) |
| | | 116 | | | 0.0749(6) | | | 0.0749(18) |
| 49 | In | 113 | | g | 0.042 88(5) 2s N | 49 | | 0.0429(5) |
| | | 115 | | | 0.957 12(5) | | | 0.9571(5) |
| 50 | Sn | 112 | | g | 0.009 73(3) 1s C | 50, 51 | | 0.0097(1) |
| | | 114 | | | 0.006 59(3)[f] | | | 0.0066(1) |
| | | 115 | | | 0.003 39(3)[f] | | | 0.0034(1) |
| | | 116 | | | 0.145 36(31) | | | 0.1454(9) |
| | | 117 | | | 0.076 76(22) | | | 0.0768(7) |
| | | 118 | | | 0.242 23(30) | | | 0.2422(9) |
| | | 119 | | | 0.085 85(13) | | | 0.0859(4) |
| | | 120 | | | 0.325 93(20) | | | 0.3258(9) |
| | | 122 | | | 0.046 29(9) | | | 0.0463(3) |
| | | 124 | | | 0.057 89(17) | | | 0.0579(5) |
| 51 | Sb | 121 | | g | 0.572 13(32) 2s C | 52 | | 0.5721(5) |
| | | 123 | | | 0.427 87(32) | | | 0.4279(5) |
| 52 | Te | 120 | | g | 0.000 96(1)[h] 2se N | 53 | | 0.0009(1) |
| | | 122 | | | 0.026 03(1)[h] | | | 0.0255(12) |
| | | 123 | | | 0.009 08(1)[h] | | | 0.0089(3) |
| | | 124 | | | 0.048 16(2)[h] | | | 0.0474(14) |
| | | 125 | | | 0.071 39(2)[h] | | | 0.0707(15) |
| | | 126 | | | 0.189 52(4)[h] | | | 0.1884(25) |
| | | 128 | | | 0.316 87(4)[h] | | | 0.3174(8) |
| | | 130 | | | 0.337 99(3)[h] | | | 0.3408(62) |
| 53 | I | 127 | | | 1.0000 | 54 | | 1.0000 |
| 54 | Xe | 124 | | g,m | 0.000 952(3) 3s C | 55 | | 0.000 952(3) |
| | | 126 | | | 0.000 890(2) | | | 0.000 890(2) |
| | | 128 | | | 0.019 102(8) | | | 0.019 102(8) |
| | | 129 | | | 0.264 006(82) | | | 0.264 006(82) |
| | | 130 | | | 0.040 710(13) | | | 0.040 710(13) |
| | | 131 | | | 0.212 324(30) | | | 0.212 324(30) |
| | | 132 | | | 0.269 086(33) | | | 0.269 086(33) |
| | | 134 | | | 0.104 357(21) | | | 0.104 357(21) |
| | | 136 | | | 0.088 573(44) | | | 0.088 573(44) (in air) |
| 55 | Cs | 133 | | | 1.0000 | 19 | | 1.0000 |
| 56 | Ba | 130 | | g | 0.001 058(2) 3se F | 56 | | 0.001 06(1) |
| | | 132 | | | 0.001 012(2) | | | 0.001 01(1) |
| | | 134 | | | 0.024 17(3) | | | 0.024 17(18) |
| | | 135 | | | 0.065 92(2) | | | 0.065 92(12) |
| | | 136 | | | 0.078 53(4) | | | 0.078 54(24) |
| | | 137 | | | 0.112 32(4) | | | 0.112 32(24) |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | | 138 | | | 0.716 99(7) | | | 0.716 98(42) |
| 57 | La | 138 | | g | 0.000 9017(5) 2se N | 57 | | 0.000 90(1) |
| | | 139 | | | 0.999 0983(5) | | | 0.999 10(1) |
| 58 | Ce | 136 | 0.001 85–0.001 86 | g | 0.001 86(1) 2s C | 58 | | 0.001 85(2) |
| | | 138 | 0.002 51–0.002 54 | | 0.002 51(1) | | | 0.002 51(2)[g] |
| | | 140 | 0.884 46–0.884 49 | | 0.884 49(34) | | | 0.884 50(51) |
| | | 142 | 0.111 14–0.111 14 | | 0.111 14(34) | | | 0.111 14(51) |
| 59 | Pr | 141 | | | 1.0000 | 42 | | 1.0000 |
| 60 | Nd | 142 | 0.2680–0.2730 | g | 0.2716(4) 2se N | 59 | | 0.272(5) |
| | | 143 | 0.1212–0.1232 | | 0.1218(2) | | | 0.122(2)[g] |
| | | 144 | 0.2379–0.2397 | | 0.2383(4) | | | 0.238(3) |
| | | 145 | 0.0823–0.0835 | | 0.0830(2) | | | 0.083(1) |
| | | 146 | 0.1706–0.1735 | | 0.1717(3) | | | 0.172(3) |
| | | 148 | 0.0566–0.0578 | | 0.0574(1) | | | 0.057(1) |
| | | 150 | 0.0553–0.0569 | | 0.0562(1) | | | 0.056(2) |
| 61 | Pm | | | | — | | | — |
| 62 | Sm | 144 | | g | 0.030 734(9) 2s F | 60 | | 0.0307(7) |
| | | 147 | | | 0.149 934(18) | | | 0.1499(18) |
| | | 148 | | | 0.112 406(15) | | | 0.1124(10) |
| | | 149 | | | 0.138 189(18) | | | 0.1382(7) |
| | | 150 | | | 0.073 796(14) | | | 0.0738(1) |
| | | 152 | | | 0.267 421(66) | | | 0.2675(16) |
| | | 154 | | | 0.227 520(68) | | | 0.2275(29) |
| 63 | Eu | 151 | | g | 0.478 10(42) 2se C | 61 | | 0.4781(6) |
| | | 153 | | | 0.521 90(42) | | | 0.5219(6) |
| 64 | Gd | 152 | | g | 0.002 029(4) 2se N | 62 | | 0.0020(1) |
| | | 154 | | | 0.021 809(4) | | | 0.0218(3) |
| | | 155 | | | 0.147 998(17) | | | 0.1480(12) |
| | | 156 | | | 0.204 664(6) | | | 0.2047(9) |
| | | 157 | | | 0.156 518(9) | | | 0.1565(2) |
| | | 158 | | | 0.248 347(16) | | | 0.2484(7) |
| | | 160 | | | 0.218 635(7) | | | 0.2186(19) |
| 65 | Tb | 159 | | | 1.0000 | 42 | | 1.0000 |
| 66 | Dy | 156 | | g | 0.000 56(2) 2S C | 63 | | 0.000 56(3) |
| | | 158 | | | 0.000 95(2) | | | 0.000 95(3) |
| | | 160 | | | 0.023 29(12) | | | 0.023 29(18) |
| | | 161 | | | 0.188 89(28) | | | 0.188 89(42) |
| | | 162 | | | 0.254 75(24) | | | 0.254 75(36) |
| | | 163 | | | 0.248 96(28) | | | 0.248 96(42) |
| | | 164 | | | 0.2826(36) | | | 0.282 60(54) |
| 67 | Ho | 165 | | | 1.0000 | 42 | | 1.0000 |
| 68 | Er | 162 | | g | 0.001 391(30) 2s C | 64 | | 0.001 39(5) |
| | | 164 | | | 0.016 006(20) | | | 0.016 01(3) |
| | | 166 | | | 0.335 014(240) | | | 0.335 03(36) |
| | | 167 | | | 0.228 724(60) | | | 0.228 69(9) |
| | | 168 | | | 0.269 852(120) | | | 0.269 78(18) |
| | | 170 | | | 0.149 013(240) | | | 0.149 10(36) |
| 69 | Tm | 169 | | | 1.0000 | 42 | | 1.0000 |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 70 | Yb | 168 | | g | 0.001 27(2) 2se N | 59 | | 0.0013(1) |
| | | 170 | | | 0.0304(2) | | | 0.0304(15) |
| | | 171 | | | 0.1428(8) | | | 0.1428(57) |
| | | 172 | | | 0.2183(l0) | | | 0.2183(67) |
| | | 173 | | | 0.1613(7) | | | 0.1613(27) |
| | | 174 | | | 0.3183(14) | | | 0.3183(92) |
| | | 176 | | | 0.1276(5) | | | 0.1276(41) |
| 71 | Lu | 175 | | g | 0.974 16(5) 2se N | 65 | | 0.9741(2) |
| | | 176 | | | 0.025 84(5) | | | 0.0259(2) |
| 72 | Hf | 174 | 0.001 619–0.001 621 | | 0.001 620(9) 2se N | 65 | | 0.0016(1) |
| | | 176 | 0.052 06–0.052 71 | | 0.052 604(56) | | | 0.0526(7)[g] |
| | | 177 | 0.185 93–0.186 06 | | 0.185 953(12) | | | 0.1860(9) |
| | | 178 | 0.272 78–0.272 97 | | 0.272 811(22) | | | 0.2728(7) |
| | | 179 | 0.136 19–0.1363 | | 0.136 210(9) | | | 0.1362(2) |
| | | 180 | 0.350 76–0.351 | | 0.350 802(26) | | | 0.3508(16) |
| 73 | Ta | 180 | | | 0.000 123(3) 1se N | 19 | | 0.000 12(2) |
| | | 181 | | | 0.999 877(3) | | | 0.999 88(2) |
| 74 | W | 180 | | | 0.001 198(2) 1s N | 66 | | 0.0012(1) |
| | | 182 | | | 0.264 985(49) | | | 0.2650(16) |
| | | 183 | | | 0.143 136(6) | | | 0.1431(4) |
| | | 184 | | | 0.306 422(13) | | | 0.3064(2) |
| | | 186 | | | 0.284 259(62) | | | 0.2843(19) |
| 75 | Re | 185 | | | 0.373 98(16) 2s C | 67 | NIST- | 0.3740(2) |
| | | 187 | | | 0.626 02(16) | | SRM989* | 0.6260(2) |
| 76 | Os | 184 | | g,r | 0.000 197(5) 1s N | 68 | | 0.0002(1) |
| | | 186 | | | 0.015 859(44) | | | 0.0159(3) |
| | | 187 | | | 0.019 644(12) | | | 0.0196(2)[g] |
| | | 188 | | | 0.132 434(19) | | | 0.1324(8) |
| | | 189 | | | 0.161 466(16) | | | 0.1615(5) |
| | | 190 | | | 0.262 584(14) | | | 0.2626(2) |
| | | 192 | | | 0.407 815(22) | | | 0.4078(19) |
| 77 | Ir | 191 | | | 0.372 72(15) 1s N | 69 | | 0.373(2) |
| | | 193 | | | 0.627 28(15) | | | 0.627(2) |
| 78 | Pt | 190 | | | 0.000 136 34(68) 1s N | 70 | | 0.000 14(1) |
| | | 192 | | | 0.007 826 59(35) | | | 0.007 82(7) |
| | | 194 | | | 0.329 6700(77) | | | 0.329 67(99) |
| | | 195 | | | 0.338 315 57(42) | | | 0.338 32(10) |
| | | 196 | | | 0.252 4166(36) | | | 0.252 42(41) |
| | | 198 | | | 0.071 6349(42) | | | 0.071 63(55) |
| 79 | Au | 197 | | | 1.0000 | 11 | | 1.0000 |
| 80 | Hg | 196 | | | 0.001 5344(19) 1s N | 71 | | 0.0015(1) |
| | | 198 | | | 0.099 68(13) | | | 0.0997(20) |
| | | 199 | | | 0.168 73(17) | | | 0.1687(22) |
| | | 200 | | | 0.230 96(26) | | | 0.2310(19) |
| | | 201 | | | 0.131 81(13) | | | 0.1318(9) |
| | | 202 | | | 0.298 63(33) | | | 0.2986(26) |
| | | 204 | | | 0.068 65(7) | | | 0.0687(15) |
| 81 | Tl | 203 | 0.294 94–0.295 28 | | 0.295 24(9) 2s C | 72 | NIST- | 0.2952(1) |
| | | 205 | 0.704 72–0.705 06 | | 0.704 76(9) | | SRM997* | 0.7048(1) |

TABLE 1. Isotopic compositions of the elements, 2001—Continued

| *Z* | *E* | Mass number | Range of natural variations (mole fraction) | Annotations | Best measurement from a single terrestrial source (mole fraction) | Ref. | Available reference materials[a] | Representative isotopic composition (mole fraction) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 82 | Pb | 204 | 0.0104–0.0165 | g,r | 0.014 245(12) 2s C | 73 | NIST- | 0.014(1) |
| | | 206 | 0.2084–0.2748 | | 0.241 447(57) | | SRM981* | 0.241(1)[g] |
| | | 207 | 0.1762–0.2365 | | 0.220 827(27) | | NIST | 0.221(1)[g] |
| | | 208 | 0.5128–0.5621 | | 0.523 481(86) | | | 0.524(1)[g] |
| 83 | Bi | 209 | | | 1.0000 | 11 | | 1.0000 |
| 84 | Po | | | | | | | |
| 85 | At | | | | | | | |
| 86 | Rn | | | | | | | |
| 87 | Fr | | | | | | | |
| 88 | Ra | | | | | | | |
| 89 | Ac | | | | | | | |
| 90 | Th | 232 | | g | 1.0000 | 74 | | 1.0000 |
| 91 | Pa | 231 | | | 1.0000 | 75 | | 1.0000 |
| 92 | U | 234 | 0.000 050–0.000 059 | g,m,r | 0.000 054 20(42) 2s C | 76 | IRMM-184* | [0.000 054(5)] |
| | | 235 | 0.007 198–0.007 207 | | 0.007 200(1) | | CEA | [0.007 204(6)][c] |
| | | 238 | 0.992 739–0.992 752 | | 0.992 745(10) | | IRMM | [0.992 742(10)] |
| | | | | | | | NBL | |

[a]NIST materials previously were labeled NBS. IRMM materials previously were labeled CBNM. An asterisk (*) indicates the reference material used for the best measurement (column 6).

[b]Tank hydrogen has reported $^{2}$H mole fractions as low as 0.000032.

[c]Materials depleted in $^{6}$Li and $^{235}$U are commercial sources of laboratory shelf reagents. In the case of Li, such samples are known to have $^{6}$Li mole fractions in the range of 0.02007–0.07672, with natural materials at the higher end of this range. In the case of U, the $^{235}$U mole fractions are reported to range from 0.0021 to 0.007207, far removed from the natural value.

[d]CAWIA recommends that a value of 272 be employed for $^{14}$N/$^{15}$N of $N_2$ in air for the calculation of $^{15}$N mole fractions from measured $\delta\,^{15}$N values.

[e]The best measurement was derived by combining independent analyses of the $^{18}$O/$^{16}$O and $^{17}$O/$^{16}$O ratios in VSMOW.

[f]The original data for Sn were adjusted to account for possible errors due to $^{115}$In contamination, and an error in the $^{114}$Sn abundance.

[g]The abundance of this radiogenic isotope may vary substantially.

[h]An electron multiplier was used for the Te measurements and the measured abundances were adjusted by using a ‘‘square root of the masses’’ correction factor.