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INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

INORGANIC CHEMISTRY DIVISION

COMMISSION ON ATOMIC WEIGHTS AND ISOTOPIC ABUNDANCES*

ATOMIC WEIGHTS OF THE ELEMENTS 1985

*Membership of the Commission for the period 1983–1985 was as follows:

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Atomic weights of the elements 1985

Abstract - The biennial review of atomic weight, $\underline{A}_r(E)$, determinations and other cognate data have resulted in the following changes in recommended values (1983 values in parenthesis): Beryllium 9.012182 ± 3 (9.01218 ± 1); Nitrogen 14.00674 ± 7 (14.0067 ± 1); Fluorine 18.9984032 ± 9 (18.998403 ± 1); Neon 20.1797 ± 6 (20.179 ± 1); Sodium 22.989768 ± 6 (22.98977 ± 1); Magnesium 24.3050 ± 6 (24.305 ± 1); Aluminium 26.981539 ± 5 (26.98154 ± 1); Phosphorus 30.973762 ± 4 (30.97376 ± 1); Chlorine 35.4527 ± 9 (35.453 ± 1); Scandium 44.955910 ± 9 (44.95591 ± 1); Manganese 54.93805 ± 1 (54.9380 ± 1); Cobalt 58.93320 ± 1 (58.9332 ± 1); Germanium 72.61 ± 2 (72.59 ± 3); Arsenic 74.92159 ± 2 (74.9216 ± 1); Yttrium 88.90585 ± 2 (88.9059 ± 1); Niobium 92.90638 ± 2 (92.9064 ± 1); Rhodium 102.90550 ± 3 (102.9055 ± 1); Silver 107.8682 ± 2 (107.8682 ± 3); Cadmium 112.411 ± 8 (112.41 ± 1); Iodine 126.90447 ± 3 (126.9045 ± 1); Xenon 131.29 ± 2 (131.29 ± 3); Caesium 132.90543 ± 5 (132.9054 ± 1); Barium 137.327 ± 7 (137.33 ± 1); Lanthanum 138.9055 ± 2 (138.9055 ± 3); Cerium 140.115 ± 4 (140.12 ± 1); Praseodymium 140.90765 ± 3 (140.9077 ± 1); Europium 151.965 ± 9 (151.96 ± 1); Terbium 158.92534 ± 3 (158.9254 ± 1); Holmium 164.93032 ± 3 (164.9304 ± 1); Thulium 168.93421 ± 3 (168.9342 ± 1); Hafnium 178.49 ± 2 (178.49 ± 3); Gold 196.96654 ± 3 (196.9665 ± 1); Thallium 204.3833 ± 2 (204.383 ± 1); Bismuth 208.98037 ± 3 (208.9804 ± 1); Protactinium has also been assigned a standard atomic weight of 231.03588 ± 2.

These values are incorporated in the Table of Standard Atomic Weights of the Elements, 1985. The Table lists estimated uncertainties $\underline{U}_r(E)$ between ± 1 and ± 9 in the last tabulated figure in parentheses following the $\underline{A}_r(E)$ value. Annotations in Tables 1 and 2 have been changed for several of the elements. The Report summarises those elements of non-terrestrial origin for which variations in isotopic composition have been found.

INTRODUCTION

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Professor R. L. Martin from 31 August - 3 September 1985, during the XXXIII IUPAC General Assembly in Lyon, France.

It was decided not to publish a 1985 Table of Isotopic Compositions of the Elements as Determined by Mass Spectrometry, and thus, in contrast to the practice initiated in 1981, only a single Report will be presented.

The Commission has monitored the literature over the past two years and evaluated the published data on atomic weights and isotopic compositions, element by element. This has led to changes in the atomic weights and annotations of a number of elements. The atomic weight of an element can be determined from a knowledge of the isotope abundances and corresponding atomic masses of the nuclides of that element. A new compilation of the atomic masses has recently been published (Ref. 1). This has necessitated a reexamination of the atomic weights of the elements and has resulted in a number of small, but nevertheless significant changes.

The Commission at its 1981 meeting in Leuven, decided to utilize the full range of uncertainties between ± 1 and ± 9 instead of following the previous practice of restricting the listed uncertainties to either ± 1 or ± 3 in the last place. In a number of cases the latter practice has resulted in rounding up uncertainties to ± 1 or ± 3, although the evaluation of published work had yielded smaller uncertainties. In some cases, the reevaluation in uncertainties allows an additional digit to be given to the value of the atomic weight, thereby providing a more precise value.

At the 1983 Commission meeting in Lyngby, a Working Party was formed to examine the procedures which had been used to assign uncertainties to atomic weights, and to report to the Commission at this meeting on those and other procedures which might be used in the future. This Working Party met on July 26-27, 1984 at the National Bureau of Standards, Gaithersburg, Maryland, USA.

The Working Party prepared a report recommending procedures for calculating atomic weights from mass spectrometry measurements and their associated uncertainties for the polynuclidic elements, classified into four groups. These groups are dependent on the type of measurement reported and include:

(a) a measurement that was considered fully calibrated with the use of mixtures of separated isotopes of known chemical and isotopic purity,
(b) a measurement in which the "double spike" technique had been used to identify the magnitude of isotopic fractionation,
(c) a measurement which was not of the first two types but which included information on possible sources of errors, and
(d) all other measurements.

In each of these cases, suitable allowances were to be made for errors in isotope ratio measurements, fractionation errors, and uncertainties for chemical procedures with additional allowances for possible natural isotopic variations in terrestrial materials where, in the judgement of the Commission members, this was appropriate.

The Working Party also recommended a procedure for calculating the atomic weights and uncertainties of the mononuclidic elements in a uniform manner consistent with the treatment of atomic weights of other elements.A further recommendation of the Working Party was the use of single digit uncertainties from 1 to 9 applied with both signs to each tabulated atomic weight and applied equally to all elements.

As both a summary of, and addition to, their report, the Working Party prepared a set of "Technical Guidelines" which will be consulted by the full Commission in the future. In addition to the points raised above, these "Guidelines" included the provisions that the Tables of Standard Atomic Weights be as simple, easy to use, and informative as possible and, that the Commission in the future, consider making recommended changes to atomic weight or uncertainty values only if significant improvement in reliability or precision could thereby be achieved. The "Guidelines" emphasize that the collective experience and judgement of the Commission members is its most valuable asset and must be applied in each case.

The membership of the Working Party was Dr I. L. Barnes (Convenor), Dr J. R. De Laeter, Dr H.H. Ku, Mr T. J. Murphy, Mr H. S. Peiser and Dr R. Werz. The Working Party, having completed its task, has now been disbanded.

CHANGES IN THE ATOMIC WEIGHTS

Beryllium
The atomic weight and uncertainty of this mononuclidic element have been revised from 9.01218 (1) to 9.012182 (3) in the light of the new atomic mass data and the Technical Guidelines, which stipulate that the full range of uncertainties between $\pm$ 1 to $\pm$ 9 are to be used in future Atomic Weight Tables.

Boron
Although the atomic weight and uncertainty of this element has not changed, the Commission decided to add the annotation "g" because of the presence of known geological sources of boron whose atomic weight is anomalous.

Nitrogen
The atomic weight and uncertainty have been revised from 14.0067 (1) to 14.00674 (7) to be consistent with the Technical Guidelines. The annotation "r" has been added since known sources of nitrogen exist with a range of $\underline{A}_r$(N) values that prevent a more precise standard atomic weight being adopted.

Fluorine
The atomic weight and uncertainty of this mononuclidic element have been revised from 18.998403 (1) to 18.9984032 (9) in the light of the new atomic mass data and the Technical Guidelines.

Neon
In its 1961 report (Ref. 2), the Commission recommended $\underline{A}_r$(Ne) = 20.183 based on gas density measurements by Baxter and Starkweather (Ref. 3) and Baxter (Ref. 4). In 1967, the Commission (Ref. 5) noted the two calibrated measurements by Eberhardt et al. (Ref. 6) and by Walton and Cameron (Ref. 7) and recommended a value of 20.179 (3). After a thorough review of the available literature, the Commission recommended a reduced value for $\underline{U}_r$(Ne) in 1979 (Ref. 8), so that the atomic weight became 20.179 (1).

At this meeting, the Commission examined the new calibrated measurement by Bottomley et al. (Ref. 9) which gives a value for the atomic weight of neon of 20.1800 (6), in excellent agreement with the previous two calibrated measurements. The Commission feels justified in recommending a more precise value which is essentially the average of the three calibrated measurements and now recommends $\underline{A}_r$(Ne) = 20.1797 (6).

Although no variations in commercial sources of neon have been found, a number of anomalous samples are known (Ref. 10) and the atomic weight carries an annotation of "g".

Sodium

The atomic weight and uncertainty of this mononuclidic element have been revised from 22.98977 (1) to 22.989768 (6) in the light of the new atomic mass data and the Technical Guidelines.

Magnesium

The atomic weight and uncertainty have been revised from 24.305 (1) to 24.3050 (6) to be consistent with the Technical Guidelines.

Aluminium

The atomic weight and uncertainty of this mononuclidic element have been revised from 26.98154 (1) to 26.981539 (5) in the light of the new atomic mass data and the Technical Guidelines.

Phosphorus

The atomic weight and uncertainty of this mononuclidic element have been revised from 30.97376 (1) to 30.973762 (4) in the light of the new atomic mass data and the Technical Guidelines.

Chlorine

The atomic weight and uncertainty have been revised from 35.453 (1) to 35.4527 (9) to be consistent with the Technical Guidelines.

Scandium

The atomic weight and uncertainty of this mononuclidic element have been revised from 44.95591 (1) to 44.955910 (9) in the light of the new atomic mass data and the Technical Guidelines.

Manganese

The atomic weight and uncertainty of this mononuclidic element have been revised from 54.9380 (1) to 54.93805 (1) in the light of the new atomic mass data and the Technical Guidelines.

Cobalt

The atomic weight and uncertainty of this mononuclidic element have been revised from 58.9332 (1) to 58.93320 (1) in the light of the new atomic mass data and the Technical Guidelines.

Germanium

In its 1961 report (Ref. 2), the Commission recommended $\underline{A}_r$(Ge) = 72.59 based on chemical ratio determinations by Baxter and Cooper (Refs. 11,12), Hönigschmid et al.(Ref. 13) and Hönigschmid and Wintersberger (Ref. 14). In 1969, the Commission (Ref. 15) assigned an uncertainty, $\underline{U}_r$(Ge), of 0.03, so that $\underline{A}_r$(Ge) = 72.59 (3).

In 1969 and since, the Commission has been aware of a number of mass spectrometric measurements which averaged to $\underline{A}_r$(Ge) = 72.628, in serious disagreement with the chemical values (Ref. 10). Since there was a large range in the measured values of the isotopic abundances, since germanium is a most difficult element to measure by thermal ionization mass spectrometry, and since there were no calibrated measurements available to indicate the possible magnitude of isotopic fractionation, the Commission was left without a cogent reason to increase the atomic weight value of germanium.

A recent publication by Green et al. (Ref. 16) generally confirms the previous mass spectrometric work by Inghram et al. (Ref. 17), Hibbs et al. (Ref. 18), Graham et al. (Ref. 19), Dibeler (Ref. 20), Reynolds (Ref. 21) and Shima (Ref. 22), after allowance for known sources of isotope discrimination. The Commission now judges that a higher value of $\underline{A}_r$(Ge) = 72.61 (2) contains the most probable value and recommends this value. The Commission noted that there is still concern about the discrepancy between the chemical value and that determined by mass spectrometry and, while not wishing to discard the chemical work, now favours the mass spectrometric one. The Commission urges that further work be undertaken, in particular, a calibrated measurement of the isotopic abundances of germanium. The Commission also noted that an independent measurement, that of equating the density of the structural crystal cell of elemental germanium with its macroscopic density (Ref. 23) gives a value in accord with the new recommended value.

Green et al., using a double spike, compared the isotopic abundances of germanium in 12 materials ranging from germanium minerals to various reagents to transistor germanium, and found no variations outside of experimental error. Shima and Graham et al. had previously also found no natural variations in a number of samples examined.

Arsenic

The atomic weight and uncertainty of this mononuclidic element have been revised from 74.9216 (1) to 74.92159 (2) in the light of the new atomic mass data and the Technical Guidelines.

Strontium

The radioactive isotope ^{87}Rb decays to ^{87}Sr with a half-life of 4.88×10^{10}a. Because varying amounts of rubidium in natural sources of strontium have enriched the ^{87}Sr isotope (Ref 10), the annotation "r" is added because known sources of strontium exist with a range in $\underline{A}_r$(Sr) values that prevent a more precise standard atomic weight being adopted.

The footnote "r" thus not only explains why a more precise standard atomic weight cannot now or in future years be tabulated, but it also implies that a chemist in need of a more precise atomic weight for a specific sample or source could obtain such a value by experimental determination.

Yttrium

The atomic weight and uncertainty of this mononuclidic element have been revised from 88.9059 (1) to 88.90585 (2) in the light of the new atomic mass data and Technical Guidelines.

Niobium

The atomic weight and uncertainty of this mononuclidic element have been revised from 92.9064 (1) to 92.90638 (2) in the light of the new atomic mass data and Technical Guidelines.

Rhodium

The atomic weight and uncertainty of this mononuclidic element have been revised from 102.9055 (1) to 102.90550 (3) in the light of the new atomic mass data and Technical Guidelines.

Silver

The atomic weight and uncertainty have been revised from 107.8682 (3) to 107.8682 (2) to be consistent with the Technical Guidelines.

Cadmium

In 1975 (Ref. 24) the Commission recommended $\underline{A}_r$(Cd) = 112.41 (1), based on the calibrated isotopic composition measurements of Rosman and De Laeter (Ref. 25) who used a double-spike technique to correct for mass discrimination. The atomic weight calculated from this work and masses from Wapstra and Bos (Ref. 26) was $\underline{A}_r$(Cd) = 112.410 (4). The authors found no significant differences between the isotopic compositions of eight mineral samples and a laboratory standard. Since then another confirmatory measurement of abundances has been made by Rosman et al. (Ref. 27) which gives $\underline{A}_r$(Cd) = 112.412 (4). The Commission has reexamined these data and, with its liberalized policy on single digit uncertainties, now recommends $\underline{A}_r$(Cd) = 112.411 (8) for the standard atomic weight.

Indium

The isotopic composition of this element has not been measured in uranium ore zone samples from the natural nuclear reactor at Oklo in Gabon, and although on theoretical grounds it is expected that anomalous samples may exist, nevertheless the annotation "g" previously used for this element has been suppressed until such measurements are made.

Tin

De Laeter et al. (Ref. 28) measured tin in uranium ore zone samples from the natural nuclear reactor at Oklo in Gabon, and showed that fission product-induced isotopic anomalies exist. Thus the annotation "g" is justified for this element.

Iodine

The atomic weight and uncertainty of this mononuclidic element have been revised from 126.9045 (1) to 126.90447 (3) in the light of the new atomic mass data and the Technical Guidelines.

Xenon

The uncertainty associated with $\underline{A}_r$(Xe) has been revised from 131.29 (3) to 131.29 (2) to be consistent with the Technical Guidelines.

Caesium
The atomic weight and uncertainty of this mononuclidic element have been revised from 132.9054 (1) to 132.90543 (5) in the light of the new atomic mass data and the Technical Guidelines.

Barium
The Commission, in 1961, recommended a value of 137.34 for the atomic weight of barium (Ref. 2). This was based both on the chemical data of Hönigschmid and Sachtleben (Ref. 29), and on mass spectrometric abundance measurements by Nier (Ref. 30) and by Thode (Ref. 31). In 1969, the Commission assigned an uncertainty so that the value became $\underline{A}_r$(Ba) = 137.34 (3), (Ref. 15).

In 1975, the Commission reviewed the above data as well as new mass spectrometric measurements by Rider et al. (Ref. 32), Umemoto (Ref. 33), Eugster et al. (Ref. 34) and De Laeter and Date (Ref. 35). All of these measurements fell within a very narrow range and that by Eugster et al. had been calibrated by the double spike technique. As a result, the Commission recommended $\underline{A}_r$(Ba) = 137.33 (1) (Ref. 24). Eugster et al. and De Laeter and Date had reported no isotopic variations in a range of terrestrial and meteoritic samples.

At this meeting, the Commission, under its new rules permitting the use of uncertainties from 1 to 9, again reviewed the available data and felt that an additional digit was justified, and recommended $\underline{A}_r$(Ba) = 137.327 (7).

The atomic weight of barium has carried the annotation "g" on what the Commission has, in the past, felt were strong theoretical grounds that fission product barium should exist in samples from the Oklo deposits. There have, however, been numerous unsuccessful experimental attempts to measure this fission product barium. Thus the annotation "g" previously used for this element has been suppressed.

Lanthanum
The uncertainty associated with $\underline{A}_r$(La) has been revised from 138.9055 (3) to 138.9055 (2) to be consistent with the Technical Guidelines.

Cerium
The atomic weight and uncertainty have been revised from 140.12 (1) to 140.115 (4) to be consistent with the Technical Guidelines.

Praseodymium
The atomic weight and uncertainty of this mononuclidic element have been revised from 140.9077 (1) to 140.90765 (3) in the light of the new atomic mass data and the Technical Guidelines.

Europium
The atomic weight and uncertainty have been revised from 151.96 (1) to 151.965 (9) to be consistent with the Technical Guidelines.

Terbium
The atomic weight and uncertainty of this mononuclidic element have been revised from 158.9254 (1) to 158.92534 (3) in the light of the new atomic mass data and the Technical Guidelines.

Holmium
The atomic weight and uncertainty of this mononuclidic element have been revised from 164.9304 (1) to 164.93032 (3) in the light of the new atomic mass data and the Technical Guidelines.

Thulium
The atomic weight and uncertainty of this mononuclidic element have been revised from 168.9342 (1) to 169.93421 (3) in the light of the new atomic mass data and the Technical Guidelines.

Hafnium
The uncertainty associated with $\underline{A}_r$(Hf) has been revised from 178.49 (3) to 178.49 (2) to be consistent with the Technical Guidelines.

Gold
The atomic weight and uncertainty of this mononuclidic element have been revised from 196.9665 (1) to 196.96654 (3) in the light of the new atomic mass data and the Technical Guidelines.

Thallium
The atomic weight and uncertainty have been revised from 204.383 (1) to 204.3833 (2) to be consistent with the Technical Guidelines.

Bismuth
The atomic weight and uncertainty of this mononuclidic element have been altered from 208.9804 (1) to 208.98037 (3) in the light of the new atomic mass data and the Technical Guidelines.

Thorium
Because of the presence of the radioactive nuclide ^{230}Th, (half-life 7.54 x 10^4 a), which is in the ^{238}U decay series and in equilibration with ^{234}U, the Commission's policy on mononuclidic elements could not apply to thorium. Average Th/U ratios of normal terrestrial materials reported are 1-7 (Ref.36), which gives the atomic weight of thorium as 232.0380180 - 232.0380461. Therefore, the Commission decided to add the footnote r to this element, and retain the atomic weight as 232.0381 (1). The footnote "X" in the 1983 Table has been altered to "Z" and the statement has been modified accordingly.

Protactinium
An atomic weight for protactinium was first entered in the IUPAC Table for 1969 (Ref. 15). The value $\underline{A}_r$(Pa) = 231.0359 was annotated "mononuclidic element" and "most commonly available long-lived isotope". ^{231}Pa is an α-emitter with a half-life of 3.28 x 10^4a (Ref. 37), too short for the survival of primordial protactinium. Nevertheless ^{231}Pa, in the radioactive decay series of ^{235}U, is a well-known, if rare, element. Its chemistry has been studied in great detail (Ref. 38).

So far only one other isotope of protactinium has been shown to be naturally occurring: ^{234}Pa in the radioactive decay series of ^{238}U has a half-life of about 1.2 m with a minor isomer which has a 6.75 h half-life. Thus, with every gram of natural uranium there is in equilibrium 2 x 10^{-16}g of ^{234}Pa. Even that vanishes rapidly after chemically separating protactinium. Apart from minor rewording of annotations, the Commission in its Reports left unchanged the entry for protactinium until 1983.

In the 1983 Report (Ref. 37) however, the Commission decided to discontinue the listing of the atomic weights of all elements without stable isotopes except thorium and uranium. The reason was that most of these radioactive elements are produced in the form of different isotopes by different nuclear reactions. ^{233}Pa too had been produced in weighable amounts (Ref. 38) from the (n,γ) reaction on ^{232}Th. ^{233}Pa has a half-life of only 27 days, but that is longer than the half-lives of the eighteen other known isotopes of protactinium, except ^{231}Pa. ^{233}Pa has not been proved to be naturally occurring, where it might be an exceedingly rare decay product of ^{237}Np.

In 1985 the Commission took note that protactinium, like thorium and uranium, has a unique naturally-occurring isotopic composition: 100% ^{231}Pa. Even in the presence of excess natural uranium, this gives an atomic weight to more than eight-figure accuracy. The Commission has therefore treated protactinium as a "pseudo-mononuclidic element" for the purpose of tabulating atomic weights which is now given as: $\underline{A}_r$(Pa) = 231.03588(2).

Uranium
The atomic weight, uncertainties and annotations "g" and "m" for this element remain unchanged. However the footnote "Y" in the 1983 Table has been altered to "Z" and the statement has been modified accordingly.

THE TABLE OF STANDARD ATOMIC WEIGHTS 1985

The changes referred to above are incorporated into the 1985 Table of Standard Atomic Weights. Following past practice, the Table is presented both in alphabetical order by English names of the elements (Table 1) and in the order of atomic number (Table 2).

In the 1983 Report, the Commission stressed the importance of accurate isotopic composition measurements in order to improve the accuracy of the atomic weight of certain elements, and this is reiterated in this Report.

TABLE 1. Standard Atomic Weights 1985
(Scaled to $\underline{A}_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $\underline{A}_r(E)$ and $\underline{U}_r(E)$ given here apply to elements as they exist naturally on earth.

Alphabetical order in English

Names	Symbol	Atomic Number	Atomic Weight	Footnotes
Actinium*	Ac	89		A
Aluminium	Al	13	26.981539 (5)	
Americium*	Am	95		A
Antimony (Stibium)	Sb	51	121.75 (3)	
Argon	Ar	18	39.948 (1)	g r
Arsenic	As	33	74.92159 (2)	
Astatine*	At	85		A
Barium	Ba	56	137.327 (7)	
Berkelium*	Bk	97		A
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	Cs	55	132.90543 (5)	
Calcium	Ca	20	40.078 (4)	g
Californium*	Cf	98		A
Carbon	C	6	12.011 (1)	r
Cerium	Ce	58	140.115 (4)	g
Chlorine	Cl	17	35.4527 (9)	
Chromium	Cr	24	51.9961 (6)	
Cobalt	Co	27	58.93320 (1)	
Copper	Cu	29	63.546 (3)	r
Curium*	Cm	96		A
Dysprosium	Dy	66	162.50 (3)	g
Einsteinium*	Es	99		A
Element 104* (a)	Unq	104		A
Element 105* (b)	Unp	105		A
Element 106* (c)	Unh	106		A
Element 107* (d)	Uns	107		A
Erbium	Er	68	167.26 (3)	g
Europium	Eu	63	151.965 (9)	g
Fermium*	Fm	100		A
Fluorine	F	9	18.9984032 (9)	
Francium*	Fr	87		A
Gadolinium	Gd	64	157.25 (3)	g
Gallium	Ga	31	69.723 (4)	
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	114.82 (1)	
Iodine	I	53	126.90447 (3)	
Iridium	Ir	77	192.22 (3)	
Iron	Fe	26	55.847 (3)	
Krypton	Kr	36	83.80 (1)	g m
Lanthanum	La	57	138.9055 (2)	g
Lawrencium*	Lr	103		A
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		A
Mercury	Hg	80	200.59 (3)	

(a)-(d) Systematic names: (a) Unnilquadium; (b) Unnilpentium; (c) Unnilhexium; (d) Unnilseptium.

TABLE 1. Standard Atomic Weights 1985 (cont'd).

Names	Symbol	Atomic Number	Atomic Weight	Footnotes			
Molybdenum	Mo	42	95.94 (1)				
Neodymium	Nd	60	144.24 (3)	g			
Neon	Ne	10	20.1797 (6)	g	m		
Neptunium*	Np	93					A
Nickel	Ni	28	58.69 (1)				
Niobium	Nb	41	92.90638 (2)				
Nitrogen	N	7	14.00674 (7)	g		r	
Nobelium*	No	102					A
Osmium	Os	76	190.2 (1)	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)				
Plutonium*	Pu	94					A
Polonium*	Po	84					A
Potassium (Kalium)	K	19	39.0983 (1)				
Praseodymium	Pr	59	140.90765 (3)				
Promethium*	Pm	61					A
Protactinium*	Pa	91	231.03588 (2)				Z
Radium*	Ra	88		g			A
Radon*	Rn	86					A
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)			r	
Tantalum	Ta	73	180.9479 (1)				
Technetium*	Tc	43					A
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	r		Z
Thulium	Tm	69	168.93421 (3)				
Tin	Sn	50	118.710 (7)	g			
Titanium	Ti	22	47.88 (3)				
Tungsten (Wolfram)	W	74	183.85 (3)				
Uranium*	U	92	238.0289 (1)	g	m		Z
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			

g geologically exceptional 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 considerably the implied uncertainty.

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A Radioactive elements that lack a characteristic terrestrial isotopic composition. One or more well-known isotopes are given in Table 3 with the appropriate mass and half-life.

Z An element, without stable nuclide(s), exhibiting a range of characteristic terrestrial compositions of long-lived radionuclide(s) such that a meaningful atomic weight can be given.

* Element has no stable nuclides.

TABLE 2. Standard Atomic Weights 1985

(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 footnote to this Table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ and $U_r(E)$ given here apply to elements as they exist naturally on earth.

Order of atomic number

Atomic Number	Names	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)	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	Al	26.981539 (5)	
14	Silicon	Si	28.0855 (3)	r
15	Phosphorus	P	30.973762 (4)	
16	Sulfur	S	32.066 (6)	r
17	Chlorine	Cl	35.4527 (9)	
18	Argon	Ar	39.948 (1)	g r
19	Potassium (Kalium)	K	39.0983 (1)	
20	Calcium	Ca	40.078 (4)	g
21	Scandium	Sc	44.955910 (9)	
22	Titanium	Ti	47.88 (3)	
23	Vanadium	V	50.9415 (1)	
24	Chromium	Cr	51.9961 (6)	
25	Manganese	Mn	54.93805 (1)	
26	Iron	Fe	55.847 (3)	
27	Cobalt	Co	58.93320 (1)	
28	Nickel	Ni	58.69 (1)	
29	Copper	Cu	63.546 (3)	r
30	Zinc	Zn	65.39 (2)	
31	Gallium	Ga	69.723 (4)	
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)	
43	Technetium*	Tc		A
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	114.82 (1)	
50	Tin	Sn	118.710 (7)	g
51	Antimony (Stibium)	Sb	121.75 (3)	
52	Tellurium	Te	127.60 (3)	g
53	Iodine	I	126.90447 (3)	
54	Xenon	Xe	131.29 (2)	g m
55	Caesium	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
61	Promethium*	Pm		A

TABLE 2. Standard Atomic Weights 1985 (cont'd).

Atomic Number	Names	Symbol	Atomic Weight	Footnotes
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	183.85 (3)	
75	Rhenium	Re	186.207 (1)	
76	Osmium	Os	190.2 (1)	g
77	Iridium	Ir	192.22 (3)	
78	Platinum	Pt	195.08 (3)	
79	Gold	Au	196.96654 (3)	
80	Mercury	Hg	200.59 (3)	
81	Thallium	Tl	204.3833 (2)	
82	Lead	Pb	207.2 (1)	g r
83	Bismuth	Bi	208.98037 (3)	
84	Polonium*	Po		A
85	Astatine*	At		A
86	Radon*	Rn		A
87	Francium*	Fr		A
88	Radium*	Ra		A
89	Actinium*	Ac		A
90	Thorium*	Th	232.0381 (1)	g r Z
91	Protactinium*	Pa	231.03588 (2)	Z
92	Uranium*	U	238.0289 (1)	g m Z
93	Neptunium*	Np		A
94	Plutonium*	Pu		A
95	Americium*	Am		A
96	Curium*	Cm		A
97	Berkelium*	Bk		A
98	Californium*	Cf		A
99	Einsteinium*	Es		A
100	Fermium*	Fm		A
101	Mendelevium*	Md		A
102	Nobelium*	No		A
103	Lawrencium*	Lr		A
104	Element 104* (a)	Unq		A
105	Element 105* (b)	Unp		A
106	Element 106* (c)	Unh		A
107	Element 107* (d)	Uns		A

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* Element has no stable nuclides.

(a)-(d) Systematic names: (a) Unnilquadium; (b) Unnilpentium; (c) Unnilhexium; (d) Unnilseptium.

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

The Commission has, for many years, published a Table of Relative Atomic masses and Half-Lives of Selected Radionuclides. 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 make its tabulation comprehensive. The radionuclides selected are those judged to be necessary to enable users to calculate the atomic weights of materials of abnormal or changing isotopic composition. There is no general agreement on which of the isotopes of the radioactive elements is, or is likely to be judged "important" and various criteria such as "longest half-life", "production in quantity", "used commercially", etc. will be apposite for different situations. The atomic masses are those recommended by Wapstra and Audi (Ref. 1), and the half-lives were provided by Holden (Refs. 39,40).

TABLE 3. Nuclidic Masses and Half-lives for Selected Isotopes of Elements which have no Stable Isotopes

Atomic Number	Element Name	Element Symbol	Mass No	Atomic Mass	Half Life	Units
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	1×10^2	a
			210	209.9828	138	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	3.82	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	1600	a
			228	228.0311	5.8	a
89	Actinium	Ac	227	227.0278	21.8	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	3.28×10^4	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
			244	244.0642	8.0×10^7	a
95	Americium	Am	241	241.0568	432	a
			243	243.0614	7.37×10^3	a
96	Curium	Cm	243	243.0614	28.5	a
			244	244.0627	18.1	a
			245	245.0655	8.5×10^3	a
			246	246.0672	4.7×10^3	a
			247	247.0703	1.6×10^7	a
			248	248.0723	3.8×10^5	a
97	Berkelium	Bk	247	247.0703	1.4×10^3	a
			249	249.0750	3.3×10^2	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
			242	242.0587	3.74×10^5	a
			252	252.0816	2.64	a
99	Einsteinium	Es	252	252.083	472	a
100	Fermium	Fm	257	257.0951	101	d
101	Mendelevium	Md	256	256.094	76	m
			258	258.10	55	d
102	Nobelium	No	259	259.1009	58	m
103	Lawrencium	Lr	260	260.105	3	m

TABLE 3. Nuclidic Masses and Half-lives for Selected Isotopes of Elements which have no Stable Isotopes (cont'd).

Atomic Number	Element Name	Element Symbol	Mass No	Atomic Mass	Half Life	Units
104	Element 104(a)	Unq	261	261.11	65	s
105	Element 105(b)	Unp	262	262.114	34	s
106	Element 106(c)	Unh	263	263.118	0.9	s
107	Element 107(d)	Uns	262	262.12	0.12	s

a = years d = days h = hours m = minutes s = seconds
(a)-(d) Systematic names: (a) Unnilquadium; (b) Unnilpentium; (c) Unnilhexium; (d) Unnilseptium.

NON-TERRESTRIAL DATA

The isotopic abundances 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 analyses of meteoritic and lunar material, from space probes, from astronomical observations and from cosmic ray analysis.

The classic picture of the presolar nebula was that of a hot, well-mixed cloud of isotopically uniform composition. However, it has now been established that many elements have a different isotopic composition in non-terrestrial materials when compared with normal terrestrial materials. These anomalies may reflect primordial heterogeneities and therefore offer the possibility of identifying modes of nucleosynthesis and their associated parameters. Excellent reviews describing isotopic anomalies in non-terrestrial materials are given by Anders (Ref. 41), Begemann (Ref. 42), Clayton (Ref. 43), Pillinger (Ref. 44), Scott (Ref. 45), Wasserburg et al., (Ref. 46), Geiss and Bochsler (Ref. 47) and Wiedenbeck (Ref. 48). Fowler (Ref. 49) also touched on this problem in his Nobel lecture in Stockholm, Sweden.

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 non-terrestrial samples should exercise caution when the isotopic composition or atomic weight of a non-terrestrial sample is required.

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 current research on the isotopic variations found in non-terrestrial materials, we have chosen in this report to summarize in Table 4 a listing of experimental results for a selection of the largest reported variations. This information has been classified in terms of the major process involved in the modification of the isotopic composition of the element concerned. A listing of the major processes considered is given at the end of this section. The major process assigned to a particular datum is listed under "process" in Table 4. Thus for example, the table lists, as one of the items, the largest deviation of isotopic composition reported for the isotopes of carbon caused by a mass fractionation process, (A-1). Only data of enrichment or depletion of specific isotopes produced predominantly by one of the major alteration processes are listed. Data listed in Table 4 are limited to measured values reported in publications and in no instance represent interpolations or extrapolations.

For those interested in a more comprehensive summary of current results, their attention is directed to Shima (Ref. 50) in which is published the complete table from which Table 4 of this report was abstracted.

The five major alteration or production processes used to classify data in Table 4 are described in the following outline:-

A. <u>Mass Fractionation</u>
Mass dependent fractionation can occur both before and after the formation of the solar system.

<u>A-1</u> Fractionation by Volatilisation and Condensation.

<u>A-2</u> Fractionation by Chemical Processes: This term includes some special cases, such as the production of organic matter.

B. <u>Nuclear Reactions</u>

<u>B-1</u> Nucleosynthesis: The mechanism of formation of these nucleosynthetic materials is subject to question. Tabulated here are samples identified by the authors as products of nucleosynthesis.

<u>B-2</u> Spallation reactions: Nuclear reactions produced by galactic and solar cosmic ray bombardment prior to the fall of the meteorite.

<u>B-3</u> Low Energy Thermal Neutron Capture Reactions: Bombardment of the lunar surface or the interior of meteorites by thermal neutrons originating from cosmic rays.

C. Radioactive Decay Products

C-1 Products from extinct nuclides: When the solar system had evolved to the point where the meteorites had become closed isotopic systems some 4.6 x 10^9 years ago, some radioactive nuclides now extinct in the solar system, were still present. Daughters of such nuclides are responsible for the anomalous isotopic composition of certain elements.

C-2 Enrichments in the daughter products of radioactive nuclides which are commonly used for geochronology.

C-3 Enrichments as the result of the decay of fission products.

C-4 Preferential loss of hydrogen and other light gases from the gravitational field of the object. For example, the helium and argon in the earth's atmosphere are presently composed of very little of the original helium and argon gas but instead are composed of the outgassed helium and argon decay products from the heavy, naturally radioactive elements and from ^{40}K respectively.

D. Solar Particle Emission

D-1 Solar Wind: Lunar samples and gas rich chondrites have shown evidence of isotopic modification because of ancient and recent solar wind.

D-2 Solar Flare: During the solar event of September 23, 1978, a satellite-borne "Heavy Isotope Spectrometer Telescope" (HIST) successfully measured isotopic ratios of several elements found in the energetic particle fluxes emitted by the sun.

E. Cosmic Rays:

The recent development of high resolution detectors make it possible to measure the relative isotopic abundances of several elements for cosmic ray particles with relatively low energies (~20 to 1000 MeV/u). Data included in this category are results of cosmic ray measurements in the near-earth environment by balloon and satellite experiments.

Entries given as "δ" or "/u" (per atomic mass unit) are all in per mil (per 1000). The " δ " 's are expressed by respective mass numbers, for example, the meaning of δ(18,16) is as follows:-

$$\delta(18, 16) = \left[\frac{(^{18}O/^{16}O)_s}{(^{18}O/^{16}O)_n} - 1 \right] \times 1000$$

s: Non-terrestrial samples.
n: Terrestrial standard.

Where an isotopic ratio is given, the terrestrial value is also listed in parentheses for comparison.

TABLE 4. Maximum Isotope Variations Determined in Non-Terrestrial Materials

Element	Maximum variation measured	Materials or method of determination	Process	Reference
$_1H$	δ(2, 1); - 888	H_2 from lunar soil 10084	D-1	51
$_2He$	$^3He/^4He$ = 0.074 (1.380 x 10^{-6})	measured by spacecraft-borne detector	E	52
$_6C$	δ(13,12); + 70.2	carbonate from C1-chond. Orgueil	A-2	53
$_7N$	$^{15}N/^{14}N$ = 0.008 (0.00367)	measured by satellite-borne HIST	D-2	54
$_8O$	δ(17,16); - 42.3 δ(18,16); - 41.0	spinel in pyroxene of C3-chondrite Allende	B-1	55
$_{12}Mg$	δ(26,24); + 260	plagioclase from C3-chondrite Allende WA inclusion	C-1	56

TABLE 4. Maximum Isotope Variations Determined in Non-Terrestrial Materials (cont'd).

Element	Maximum variation measured	Materials or method of determination	Process	Reference
$_{18}Ar$	$^{40}Ar/^{36}Ar = 1.2 \times 10^{-3}$ (295.5)	1850 °C release from carbon-rich residue of ureilite Dyalpur	C-4	57
$_{20}Ca$	7.5 / u	HAL inclusion of Allende	A-1	58
$_{23}V$	$^{51}V/^{50}V = 4.3$ (399)	iron meteorite Grant surface	B-2	59
$_{38}Sr$	$^{87}Sr/^{86}Sr = 8.45$ (0.7099)	silicate inclusion of iron meteorite Colomela	C-2	60
$_{54}Xe$	$^{136}Xe/^{132}Xe = 0.6167$ (0.331)	600°C release from <2.89g/cm³ density f. of C3-chond. Allende	C-3	61
$_{64}Gd$	$\delta(158,157)$; + 5.97	lunar rock, 10017,56	B-3	62

OTHER PROJECTS OF THE COMMISSION

The Commission decided to initiate three new projects at the Lyon meeting. A Sub-Committee for Isotopic Abundance Measurements (SIAM) was established to identify and assess experimental methods leading to isotope abundances and/or atomic weights and to critically evaluate any new data pertaining to the work of the Commission.

A Working Party on Measurements, Sensors and Measuring Instruments was formed to produce a report on "Uncertainty in Chemical Measurements". This Working Party will report through the Commission to the Division.

Another Working Party on Natural Isotopic Fractionation was established to investigate the impact of the variation in isotopic abundance of compounds of an element on the determination of the atomic weight of the element and the uncertainty thereof.

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