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COMMISSION ON ATOMIC WEIGHTS AND ISOTOPIC ABUNDANCES*

ATOMIC WEIGHTS OF THE ELEMENTS 1981

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ATOMIC WEIGHTS OF THE ELEMENTS 1981

Abstract - The biennial review of atomic weight, $A_r(E)$, determinations and other cognate data have resulted in the following changes in recommended values (1979 values in parentheses): Hydrogen 1.00794 ± 7 (1.0079 ± 1); Silver 107.8682 ± 3 (107.868 ± 1); Lutetium 174.967 ± 1 (174.967 ± 3). These values are incorporated in the Table of Standard Atomic Weights of the Elements 1981. Whereas in the past, the Table indicated uncertainties as either 1 or 3 in the last place, other single-digit uncertainties will in the future be quoted when there is convincing evidence that by their use, a more precise standard atomic weight can be tabulated. Important changes in annotations and the wording of footnotes to this Table and the Table of Isotopic Compositions are discussed. Changes in $A_r(E)$ values and in their estimated uncertainties in the period since 1969 are analysed. The Report includes for the first time a Table of Atomic Weights abbreviated to five significant figures in the expectation that changes in the tabulated data will rarely be needed. Attention is drawn to the possibility of materials being commercially available containing elements with unusual atomic weights due to the enrichment or depletion of isotopes by free radical magnetic effects. The Relative Atomic Masses for Selected Radioisotopes are also tabulated.

INTRODUCTION

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Dr. N.E. Holden on 26-29 August 1981 during the XXXI IUPAC General Assembly in Leuven, Belgium. The Commission decided to depart from previous practice by presenting its Report for 1981 in two Parts, the first containing the 1981 Table of Standard Atomic Weights of the Elements and other cognate data, and the second, providing the 1981 Table of Isotopic Compositions and Atomic Weights as determined by mass spectrometry.

During the past two years the Commission has continued to review the literature and evaluate the published data on atomic weights and isotopic compositions element by element. As a result of its assessment, the recommended values for the standard atomic weights of three elements were changed and for one element, a footnote was appended. The justifications for these changes are set out in the next Section and this is followed by the definitive Table of Standard Atomic Weights of the Elements, 1981.

The Commission has for several years stressed the problems arising from the potential or actual variability of the atomic weights of many elements. Various annotations to the tabulated values have been devised to alert readers to these problems and, in the Section of the Report on the new Table of Standard Atomic Weights, the philosophy behind these footnotes is reviewed. The Commission has decided to introduce, for the time being, a minimum and coherent set of single-symbol footnotes which are harmonized between the Tables of Standard Atomic Weights and the Table of Isotopic Compositions.

The Commission's policy of recommending the greatest precision that can be reasonably supported by published measurements inevitably leads to a wide variation in the precision with which the atomic weights of the naturally occurring elements can be tabulated. Changes in the estimated reliabilities of the recommended atomic weights of the elements which have occurred since 1969 are reviewed in this Section of the Report. The changes in recommended atomic weight values since estimates of uncertainties were first consistently applied in 1969 are also surveyed.

The Commission indicated its intention in the 1979 Report (Ref. 1) of publishing, in due course, a table of atomic weights expressed to no more than five significant figures. This Table has now been prepared and is presented in the next Section in order to provide practicing chemists and others with all their needed but not superfluous data in the hope that the $A_r(E)$ values listed will remain unchanged, at least for a number of years. The practice of tabulating the relative atomic masses of selected nuclides is continued in this Part of the Report, confining these to certain nuclides of radioactive elements, including those such as technetium, promethium and the elements of highest atomic number, for which the Table of Standard Atomic Weights lists only an atomic mass number in parenthesis.

The possibility of isotopic enrichment or depletion due to a combination of chemical and magnetic effects is mentioned, and Part 1 of the Report concludes with a brief commentary on the rich and rapidly expanding body of knowledge on the values of isotopic abundances of elements from non-terrestrial sources.

CHANGES IN ATOMIC WEIGHT VALUES

Hydrogen

The value of $\underline{A_r}$(H) = 1.0079 ± 0.0001 for the atomic weight of hydrogen was adopted by the Atomic Weights Commission in its 1971 Report (Ref. 2) to encompass all normal samples, whereas the previous value 1.0080 ± 0.0001 did not. Although the value 1.0079 is close to the atomic weight of laboratory hydrogen gas which may have been depleted of deuterium by electrolysis ($\underline{A_r}$(H) = 1.00787), it does not represent with the same accuracy the atomic weight of hydrogen from fresh water in temperate climates or in sea water ($\underline{A_r}$(H) = 1.00798). In order to improve precision, the Commission recommends the value $\underline{A_r}$(H) 1.00794 ± 0.00007 for the atomic weight of hydrogen. The quoted uncertainty covers the range of all terrestrial aqueous and gaseous sources of hydrogen. Only very exceptional geological samples may yield hydrogen with values outside this range.

It may be noted that an uncertainty of 7 in the last place for hydrogen corresponds to a departure from previous Commission policy of quoting uncertainties as either 1 or 3. It is anticipated that other single digit uncertainties may be quoted in the future for other elements when there is convincing evidence that by their use, a more precise standard atomic weight can be tabulated.

Silver

The 1961 Report (Ref. 3) contained an extensive review of the atomic weights of silver, chlorine and bromine because of the historical relation of these elements, i.e. the atomic weights of many elements were determined from their combining ratios with silver, chlorine, and bromine. The Commission recommended a value of $\underline{A_r}$(Ag) = 107.870 ± 0.003, intermediate between the recalculated average of the chemical determinations (107.8714) and the physical measurement of 107.8685 ± 0.0013 by Shields, Craig and Diebler (Ref. 4). In 1967, with physical measurements of the absolute abundance ratios of bromine and chlorine completed, the Commission recommended a value of 107.868 ± 0.001 (Ref. 5). They noted that this value had been confirmed by the work Crouch and Turnbull who had obtained a value of 0.001 higher (107.8694 ± 0.0026) with a somewhat higher uncertainty (Ref. 6). In 1969 the Commission, after assessing the uncertainties given for the atomic weights of all the elements, reconfirmed a value of 107.868 ± 0.001 (Ref. 7).

At this meeting, the Commission considered a new determination of the absolute abundance ratio of silver by Powell, Murphy and Gramlich (Ref. 8) who reported an atomic weight for a reference sample of silver of 107.86815 ± 0.00011 calculated from a ^{107}Ag/^{109}Ag ratio of 1.07638 ± 0.00022. These authors also reported results for a number of silver metal and mineral samples the average value of which was identical with the above number but with a slightly higher uncertainty. After careful examination of this and previous work, the Commission now recommends a value of $\underline{A_r}$(Ag) = 107.8682 ± 0.0003 for the atomic weight of silver.

Strontium

The Commission noted that Moore _et al._ (Ref. 9) had completed work on the absolute abundance ratios of a reference sample of strontium which gave an atomic weight of 87.61681 ± 0.00012 for this material. Because of known natural variations of one of the isotopes, ^{87}Sr, of this element the Commission did not feel justified in recommending a change but noted that a material with accurately known ratios is now available.

Lutetium

The value of $\underline{A_r}$(Lu) 174.97 for the atomic weight of lutetium was adopted by the Atomic Weights Commission in its 1961 Report (Ref. 3). This was modified subsequently to $\underline{A_r}$(Lu) 174.97 ± 0.01 (Ref. 7). In the 1977 Report, the atomic weight was changed to $\underline{A_r}$(Lu) = 174.967 ± 0.003 (Ref. 10) on the basis of a new measurement by McCulloch _et al._ (Ref. 11). Hollinger and Devillers have recently redetermined the isotopic composition of lutetium although the absolute abundances of the lutetium isotopes were not determined (Ref. 12). The good agreement in the mass spectrometric measurement together with the distribution of the abundances and the consequent probability of only a minor mass discrimination effect, has enabled the Commission to recommend $\underline{A}_r$(Lu) = 174.967 ± 0.001 as the most precise but still reliable value for lutetium.

CHANGES IN FOOTNOTES

Neon

As mentioned in the 1979 Report (Ref. 1), the atomic weight of neon has a recommended value of $\underline{A}_r$(Ne) = 20.179 ± 0.001 as the most precise but still reliable value. Neon from some geological specimens has an isotopic composition which leads to atomic weight values which are outside the implied range. The Commission retains the previously recommended atomic weight but now adds the footnote g to account for neon from exceptional geological specimens (Ref. 25).

THE TABLE OF STANDARD ATOMIC WEIGHTS 1981

The changes referred to above are incorporated in the 1981 Table of Standard Atomic Weights. Following past practice, the Table is presented both in alphabetic order by English names of the elements (Table 1) and in the order of atomic number (Table 2). During the past two years, the Commission's Subcommittee for the Assessment of Isotopic Composition (SAIC) has been reviewing in detail the atomic weights for all the elements in the light of all new and existing experimental data.

A change in the 1981 Tables which the Commission has been debating for some years concerns a general policy regarding the annotations and wording of footnotes. The basic need for annotations to the Atomic Weights Tables and the Table of Isotopic Compositions arises from the necessity to impart to users additional information that is relevant to one or more elements but that cannot be made readable from numerical data in the columns. Any desire to maximize that additional information conveyed by these Tables is tempered by the need to preserve a compact format and a style that can alert the casual, yet possibly affected reader, who would look up neither the last full element by element review statement nor even the full text of a current Report.

The existing footnotes fail to give some details, such as the magnitudes or signs of differences between normal and abnormal atomic weight values or ranges, geological locations, abundancy of commercially available but abnormal sources, etc. Such additional information to be conveyed to users of these Tables will multiply in future years as materials from nuclear technologies, extra-terrestrial sources, and interest in trace-element compositions of isotopes and products from vacuum, vapor-path and other fractionations become more widespread.

A simple set of one-letter symbols has failed in the past, and certainly will fail in the future, to satisfy fully the Commission's wish to convey to users of the Tables the diversity of factual information with appropriate nuances. The Commission, while not adopting a more satisfying versatile method of annotations now, may reconsider it later for annotating the Tables based on a selection of information from a full element by element review of all significant publications on atomic weight determinations. Such a review was published in 1961 by A.E. Cameron and E. Wichers (Ref. 3) but needs to be updated. This considerable task is currently being undertaken by the Commission's Subcommittee for the Assessment of Isotopic Composition (SAIC). In the meanwhile, in Parts 1 and 2 of this Report the Commission believes its purposes will be served by using a minimum and coherent set of single-symbol annotations harmonized between the Tables of Standard Atomic Weights (Part 1) and the Table of Isotopic Compositions (Part 2). The same phenomena (range of isotopic abundances, etc.) give rise to the necessity for these annotations in both Parts of this Report. But they apply in this first Part to a smaller number of elements because variations in isotopic composition have to be larger to alter significantly atomic weights than are needed to affect measured isotopic abundances. Therefore, the same letters have been used for the annotations in both tables. To help users to memorize and identify the letters, they are chosen as the first letters of words associated with the phenomena necessitating their appendage. Some distinction is maintained between the tables by the use of lower case letters for the Table of Standard Atomic Weights and capital letters for the Table of Isotopic Compositions. Only capital "L" is used in both tables because it applies to exactly the same elements in both.

The Commission's policy of recommending the greatest precision that can reasonably be supported by published measurements inevitably leads to a wide variation in the precision with which the atomic weights of the naturally occurring elements can be tabulated. In its 1971 (Ref. 2) and 1975 (Ref. 13) Reports, the Commission published plots of relative uncertainties of the then atomic weights of all the elements with stable nuclides. A similar but circular graph (see Fig. 1) of the relative uncertainties in the Standard Atomic Weights of the Elements and their progression during the period 1969-1981 is presented in

Table 1. Standard Atomic Weights 1981

(Scaled to the relative atomic mass, 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 $A_r(E)$ given here apply to elements as they exist naturally on earth and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit, unless otherwise noted. Values in parentheses are used for radioactive elements whose atomic weights cannot be quoted precisely without knowledge of the origin of the elements; the value given is the atomic mass number of the isotope of that element of longest known half life.

Alphabetical order in English

Names	Symbol	Atomic number	Atomic weight	Footnotes
Actinium	Ac	89	227.0278	L
Aluminium	Al	13	26.98154	
Americium	Am	95	(243)	
Antimony (Stibium)	Sb	51	121.75 ± 3	
Argon	Ar	18	39.948	g r
Arsenic	As	33	74.9216	
Astatine	At	85	(210)	
Barium	Ba	56	137.33	g
Berkelium	Bk	97	(247)	
Beryllium	Be	4	9.01218	
Bismuth	Bi	83	208.9804	
Boron	B	5	10.81	m r
Bromine	Br	35	79.904	
Cadmium	Cd	48	112.41	g
Caesium	Cs	55	132.9054	
Calcium	Ca	20	40.08	g
Californium	Cf	98	(251)	
Carbon	C	6	12.011	r
Cerium	Ce	58	140.12	g
Chlorine	Cl	17	35.453	
Chromium	Cr	24	51.996	
Cobalt	Co	27	58.9332	
Copper	Cu	29	63.546 ± 3	r
Curium	Cm	96	(247)	
Dysprosium	Dy	66	162.50 ± 3	
Einsteinium	Es	99	(252)	
Erbium	Er	68	167.26 ± 3	
Europium	Eu	63	151.96	g
Fermium	Fm	100	(257)	
Fluorine	F	9	18.998403	
Francium	Fr	87	(223)	
Gadolinium	Gd	64	157.25 ± 3	g
Gallium	Ga	31	69.72	
Germanium	Ge	32	72.59 ± 3	
Gold	Au	79	196.9665	
Hafnium	Hf	72	178.49 ± 3	
Helium	He	2	4.00260	g
Holmium	Ho	67	164.9304	
Hydrogen	H	1	1.00794 ± 7	g m r
Indium	In	49	114.82	g
Iodine	I	53	126.9045	
Iridium	Ir	77	192.22 ± 3	
Iron	Fe	26	55.847 ± 3	
Krypton	Kr	36	83.80	g m
Lanthanum	La	57	138.9055 ± 3	g
Lawrencium	Lr	103	(260)	
Lead	Pb	82	207.2	g r
Lithium	Li	3	6.941 ± 3	g m r
Lutetium	Lu	71	174.967	
Magnesium	Mg	12	24.305	g
Manganese	Mn	25	54.9380	
Mendelevium	Md	101	(258)	
Mercury	Hg	80	200.59 ± 3	
Molybdenum	Mo	42	95.94	g

Table 1. Standard Atomic Weights 1981 (cont'd)

Names	Symbol	Atomic number	Atomic weight	Footnotes
Neodymium	Nd	60	144.24 ± 3	g
Neon	Ne	10	20.179	g m
Neptunium	Np	93	237.0482	L
Nickel	Ni	28	58.69	
Niobium	Nb	41	92.9064	
Nitrogen	N	7	14.0067	
Nobelium	No	102	(259)	
Osmium	Os	76	190.2	g
Oxygen	O	8	15.9994 ± 3	g r
Palladium	Pd	46	106.42	g
Phosphorus	P	15	30.97376	
Platinum	Pt	78	195.08±3	
Plutonium	Pu	94	(244)	
Polonium	Po	84	(209)	
Potassium (Kalium)	K	19	39.0983	
Praseodymium	Pr	59	140.9077	
Promethium	Pm	61	(145)	
Protactinium	Pa	91	231.0359	L
Radium	Ra	88	226.0254	g L
Radon	Rn	86	(222)	
Rhenium	Re	75	186.207	
Rhodium	Rh	45	102.9055	
Rubidium	Rb	37	85.4678 ± 3	g
Ruthenium	Ru	44	101.07 ± 3	g
Samarium	Sm	62	150.36 ± 3	g
Scandium	Sc	21	44.9559	
Selenium	Se	34	78.96 ± 3	
Silicon	Si	14	28.0855 ± 3	
Silver	Ag	47	107.8682 ± 3	g
Sodium (Natrium)	Na	11	22.98977	
Strontium	Sr	38	87.62	g
Sulfur	S	16	32.06	r
Tantalum	Ta	73	180.9479	
Technetium	Tc	43	(98)	
Tellurium	Te	52	127.60 ± 3	g
Terbium	Tb	65	158.9254	
Thallium	Tl	81	204.383	
Thorium	Th	90	232.0381	g L
Thulium	Tm	69	168.9342	
Tin	Sn	50	118.69 ± 3	
Titanium	Ti	22	47.88 ± 3	
Tungsten (Wolfram)	W	74	183.85 ± 3	
(Unnilhexium)	(Unh)	106	(263)	
(Unnilpentium)	(Unp)	105	(262)	
(Unnilquadium)	(Unq)	104	(261)	
Uranium	U	92	238.0289	g m
Vanadium	V	23	50.9415	
Xenon	Xe	54	131.29 ± 3	g m
Ytterbium	Yb	70	173.04 ± 3	
Yttrium	Y	39	88.9059	
Zinc	Zn	30	65.38	
Zirconium	Zr	40	91.22	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.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. 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 atomic weight being given; the tabulated A_r(E) value should be applicable to any normal material.

L Longest half-life isotope mass is chosen for the tabulated A_r(E) value.

TABLE 2. Standard Atomic Weights 1981

(Scaled to the relative atomic mass $\underline{A}_{r}(^{12}\mathrm{C}) = 12$)

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 $\underline{A}_{r}(\mathrm{E})$ given here apply to elements as they exist naturally on earth and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit unless otherwise noted. Values in parentheses are used for radioactive elements whose atomic weights cannot be quoted precisely without knowledge of the origin of the elements; the value given is the atomic mass number of the isotope of that element of longest known half life.

Order of Atomic Number

Atomic Number	Names	Symbol	Atomic Weight	Footnotes		
1	Hydrogen	H	1.00794 ± 7	g	m	r
2	Helium	He	4.00260	g		
3	Lithium	Li	6.941 ± 3	g	m	r
4	Beryllium	Be	9.01218			
5	Boron	B	10.81		m	r
6	Carbon	C	12.011			r
7	Nitrogen	N	14.0067			
8	Oxygen	O	15.9994 ± 3	g		r
9	Fluorine	F	18.998403			
10	Neon	Ne	20.179	g	m	
11	Sodium (Natrium)	Na	22.98977			
12	Magnesium	Mg	24.305	g		
13	Aluminium	Al	26.98154			
14	Silicon	Si	28.0855 ± 3			
15	Phosphorus	P	30.97376			
16	Sulfur	S	32.06			r
17	Chlorine	Cl	35.453			
18	Argon	Ar	39.948	g		r
19	Potassium (Kalium)	K	39.0983			
20	Calcium	Ca	40.08	g		
21	Scandium	Sc	44.9559			
22	Titanium	Ti	47.88 ± 3			
23	Vanadium	V	50.9415			
24	Chromium	Cr	51.996			
25	Manganese	Mn	54.9380			
26	Iron	Fe	55.847 ± 3			
27	Cobalt	Co	58.9332			
28	Nickel	Ni	58.69			
29	Copper	Cu	63.546 ± 3			r
30	Zinc	Zn	65.38			
31	Gallium	Ga	69.72			
32	Germanium	Ge	72.59 ± 3			
33	Arsenic	As	74.9216			
34	Selenium	Se	78.96 ± 3			
35	Bromine	Br	79.904			
36	Krypton	Kr	83.80	g	m	
37	Rubidium	Rb	85.4678 ± 3	g		
38	Strontium	Sr	87.62	g		
39	Yttrium	Y	88.9059			
40	Zirconium	Zr	91.22	g		
41	Niobium	Nb	92.9064			
42	Molybdenum	Mo	95.94	g		
43	Technetium	Tc	(98)			
44	Ruthenium	Ru	101.07 ± 3	g		
45	Rhodium	Rh	102.9055			
46	Palladium	Pd	106.42	g		
47	Silver	Ag	107.8682 ± 3	g		
48	Cadmium	Cd	112.41	g		
49	Indium	In	114.82	g		
50	Tin	Sn	118.69 ± 3			
51	Antimony (Stibium)	Sb	121.75 ± 3			
52	Tellurium	Te	127.60 ± 3	g		
53	Iodine	I	126.9045			
54	Xenon	Xe	131.29 ± 3	g	m	

TABLE 2. Standard Atomic Weights 1981 (cont'd)

Atomic Number	Names	Symbol	Atomic Weight	Footnotes
55	Caesium	Cs	132.9054	
56	Barium	Ba	137.33	g
57	Lanthanum	La	138.9055 ± 3	g
58	Cerium	Ce	140.12	g
59	Praseodymium	Pr	140.9077	
60	Neodymium	Nd	144.24 ± 3	g
61	Promethium	Pm	(145)	
62	Samarium	Sm	150.36 ± 3	g
63	Europium	Eu	151.96	g
64	Gadolinium	Gd	157.25 ± 3	g
65	Terbium	Tb	158.9254	
66	Dysprosium	Dy	162.50 ± 3	
67	Holmium	Ho	164.9304	
68	Erbium	Er	167.26 ± 3	
69	Thulium	Tm	168.9342	
70	Ytterbium	Yb	173.04 ± 3	
71	Lutetium	Lu	174.967	
72	Hafnium	Hf	178.49 ±3	
73	Tantalum	Ta	180.9479	
74	Wolfram (Tungsten)	W	183.85 ± 3	
75	Rhenium	Re	186.207	
76	Osmium	Os	190.2	g
77	Iridium	Ir	192.22 ± 3	
78	Platinum	Pt	195.08 ± 3	
79	Gold	Au	196.9665	
80	Mercury	Hg	200.59 ± 3	
81	Thallium	Tl	204.383	
82	Lead	Pb	207.2	g r
83	Bismuth	Bi	208.9804	
84	Polonium	Po	(209)	
85	Astatine	At	(210)	
86	Radon	Rn	(222)	
87	Francium	Fr	(223)	
88	Radium	Ra	226.0254	g L
89	Actinium	Ac	227.0278	L
90	Thorium	Th	232.0381	g L
91	Protactinium	Pa	231.0359	L
92	Uranium	U	238.0289	g m
93	Neptunium	Np	237.0482	L
94	Plutonium	Pu	(244)	
95	Americium	Am	(243)	
96	Curium	Cm	(247)	
97	Berkelium	Bk	(247)	
98	Californium	Cf	(251)	
99	Einsteinium	Es	(252)	
100	Fermium	Fm	(257)	
101	Mendelevium	Md	(258)	
102	Nobelium	No	(259)	
103	Lawrencium	Lr	(260)	
104	(Unnilquadium)	(Unq)	(261)	
105	(Unnilpentium)	(Unp)	(262)	
106	(Unnilhexium)	(Unh)	(263)	

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.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. 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 atomic weight being given; the tabulated $A_r(E)$ value should be applicable to any normal material.

L Longest half-life isotope mass is chosen for the tabulated $A_r(E)$ value.

this Report. It indicates by arrowed lines the increase (decrease for xenon) in estimated reliability of $\underline{A}_r(E)$ values for 23 elements affected during the twelve-year period.

The footnote r implies that the uncertainty in the quoted atomic weight value cannot be reduced unless the previously credible published variability is proved erroneous or unless "atomic weight" is redefined generally or for purposes of a more precise tabulation. It will be noted that, among the elements shown with the above symbolism are Li, B, S, and Pb, four of the eight elements with the least precisely stated atomic weights.

Together with the above discussion of relative uncertainties and their improvements over recent years, it is interesting to compare the changes in actual atomic weight values $\Delta\underline{A}_r(E)$ made since estimates of uncertainties were first carefully and consistently applied in 1969. These changes affecting just 25 elements are given in Table 3. This Table includes those elements (Ti, Cd, Cs, Ho, Pt, and Bi) that have changed in $\underline{A}_r(E)$ value without change in estimated uncertainty, but excludes those elements (Ne, Ar, Mo, and Ta) that have not changed value but only their uncertainty (see Fig. 1).

Years of the biennial reports are given one column each in the Table 3. The changes made in $\underline{A}_r(E)$ values are listed with their signs as fractions of the uncertainty limits estimated in immediately prior years. The three last columns of the Table refer to the overall changes from 1969 to 1981. Of these columns, the first lists the changes as fractions relative to the 1969 uncertainties. They are not necessarily the sum of the uncertainties in the prior columns.

There are a number of points of interest to be derived from the statistical analysis of the changes. This analysis would be much easier than it is if only all the changes were based on independent sets of literature and experimental sources - which they are not - and further if only all elements had undergone at least one change since 1969 - which has not happened - and also if the new $\underline{A}_r(E)$ values were subject to substantially smaller uncertainties - which also is not always true; and finally, if the uncertainties were not numerically limited, which they have been to just 1 or 3 in the last significant figure.

Nevertheless, we can draw some conclusions from the 29 changes on 25 elements, and we can take account of the fact that the 57 elements for which no change was made, have been submitted to reviews ending in an evaluated report for each of these elements that there was no good evidence that a change would lead to a better value. Thus, the histogram (see Fig. 2) of changes in atomic weight values 1969/81 would only slightly overestimate the number of elements with changes of less than a quarter of their 1969 uncertainties if it included all 57 elements for which no change was made in these 12 years. It would at least equally underestimate that group of elements if one only counted the 7 elements for which a finite change (less than a quarter of the previously indicated uncertainty) was made.

There are 6 elements Bi, K, Cd, Xe, Cs, and Ho for which the changes in $\underline{A}_r(E)$ are equal or larger than the indicated uncertainties. Since the Commission is aiming at a 90 to 95 percent confidence limit, this figure of 6 points to an underestimate of uncertainties, till it is realized that half of that number relates to mononuclidic elements for which the absolute changes are very small - in the seventh significant figure. The Commission does not evaluate nuclidic mass data but relies on data published with the encouragement of a Commission of the International Union of Pure and Applied Physics (IUPAP) dealing with atomic masses (SUN-AMCO) (Ref. 14). If in 1969 the Atomic Weights Commission erred in its assessment of the exact interpretation of the uncertainties of these data on which the atomic weight values of the mononuclidic elements are based, the problem is really of very little significance to the users of the Standard Atomic Weights Table.

Much more serious is the fact that K also has changed by a little more (1.23 times) than the uncertainty which was assigned in 1969. However, it is the only element that is not mononuclidic for which a change since 1969 exceeds the uncertainty. Moreover, one can confidently assert that work published since then has brought knowledge of its atomic weight much closer to the true value (see the 1975 Report) so that any further fractional changes will be small relative to the 1969 uncertainty.

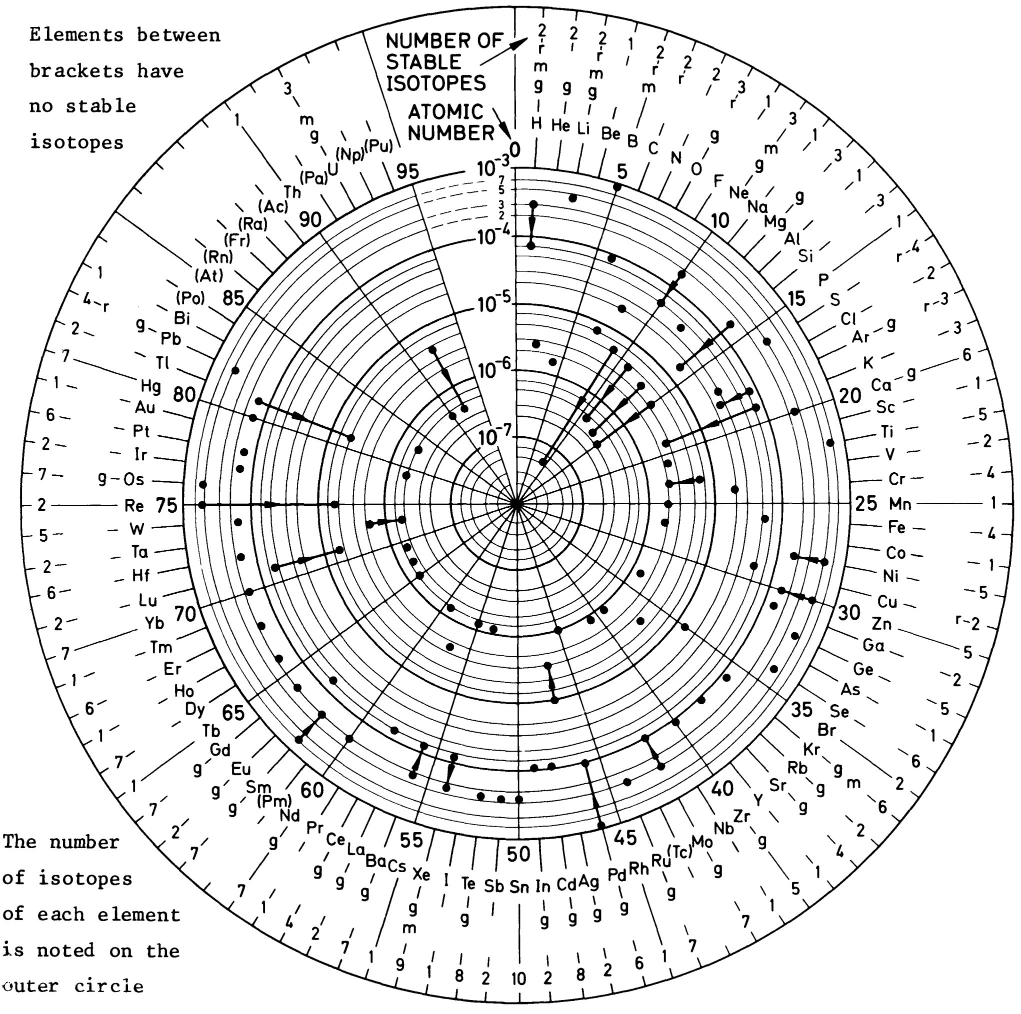
Least it be felt that for the above arguments alone it has been established that the Commission has been too conservative with the assignment of uncertainties, it should be pointed out that Ti with a smaller change of 0.67 relative to the 1969 uncertainty is still as uncertain in its new value. Further changes may be needed in future that might double or even treble the changes relative to the 1969 values. Then there is the case of Ge for which the Commission considers the evidence still not sufficiently compelling to make any change in its Standard Atomic Weight. However, in the light of recent analysis, one should not be surprised if better experimental data were to support a substantial upward adjustment of that atomic weight in absolute terms and relative to the indicated uncertainty. For these and other instances such as that of nickel, the Commission does not believe its judgment has been excessively cautious.

TABLE 3. CHANGES IN ATOMIC WEIGHT VALUES (1969-1981)

Atomic Number	Symbol	Changes as fractions of previously estimated uncertainties							1969/1981 changes	
		1971	1973	1975	1977	1979	1981	1969/1981 Overall	$\Delta A_r(E) \times 10^3$	$\Delta A_r(E) \times 10^3 / A_r(E)$
1	H	-0.33	-	-	-	-	+0.40	-0.20	-0.06	-0.060
9	F	0.0	-	+0.30	-	-	-	+0.03	+0.003	+0.00016
11	Na	-0.30	-	-	-	-	-	-0.30	-0.03	-0.0013
13	Al	+0.40	-	-	-	-	-	+0.40	+0.04	+0.0015
14	Si	-	-	-0.17	-	-	-	-0.17	-0.5	-0.018
15	P	-0.40	-	-	-	-	-	-0.40	-0.04	-0.0013
19	K	-1.33	-	+0.10	-	-	-	-1.23	-3.7	-0.095
22	Ti	-	-	-	-	-0.67	-	-0.67	-20.	-0.42
23	V	-	-	-	+0.33	-	-	+0.33	+0.1	+0.0020
28	Ni	-	-0.33	-	-	-1.00	-	-0.67	-20.	-0.34
30	Zn	+0.33	-	-	-	-	-	+0.33	+10.	+0.15
46	Pd	-	-	-	-	+0.20	-	+0.20	+20.	+0.19
47	Ag	-	-	-	-	-	+0.20	+0.20	+0.2	+0.0019
48	Cd	-	-	+1.00	-	-	-	+1.00	+10.	+0.089
54	Xe	-	-	-	-	-1.00	-	-1.00	-10.	-0.076
55	Cs	-1.00	-	-	-	-	-	-1.00	-0.1	-0.00075
56	Ba	-	-	-0.33	-	-	-	-0.33	-10.	-0.074
62	Sm	-	-	-	-	-0.40	-	-0.40	-40.	-0.27
67	Ho	+1.00	-	-	-	-	-	+1.00	+0.1	+0.00061
71	Lu	-	-	-	-0.30	-	-	-0.30	-3.	-0.017
75	Re	-	+0.07	-	-	-	-	+0.07	+7.	+0.038
78	Pt	-	-	-	-	-0.33	-	-0.33	-10.	-0.051
81	Tl	-	-	-	-	+0.43	-	+0.43	+13.	+0.064
83	Bi	-2.00	-	-	-	-	-	-2.00	-0.2	-0.00096
92	U	-	-	-	-	-0.10	-	-0.10	-0.1	-0.00042

25 elements changed out of 82

Average magnitude: ±0.52
Average over 82 elements: ±0.16



Elements between brackets have no stable isotopes

The number of isotopes of each element is noted on the outer circle

Figure 1. Changes in Relative Uncertainties of the Standard Atomic Weight Values of the Elements quoted in the IUPAC Tables during the period 1969-1981 (arrows).

- g, elements for which geological specimens are known where the element has an anomalous isotopic composition, such that the difference between atomic weight of the element in such specimens and that given in the figure may considerably exceed the implied uncertainty (e.g. helium)
- m, elements which have substantial variations in their atomic weight from the value given. These can occur in commercially available material because of inadvertent or undisclosed change of isotopic composition (e.g. neon)
- r, elements which have variations in isotopic composition in normal terrestrial material which prevent a more accurate atomic weight being given; atomic weight values should be applicable to any 'normal' material (e.g. carbon).

The footnote r implies that the uncertainty in the quoted atomic weight value cannot be reduced unless the previously credible published variability is proved erroneous or unless 'atomic weight' is redefined generally or for purposes of a more precise tabulation. It will be noted that, among the elements shown with the above symbolism are Li, B, S, Pb, four of the nine elements with the least precisely stated atomic weights.

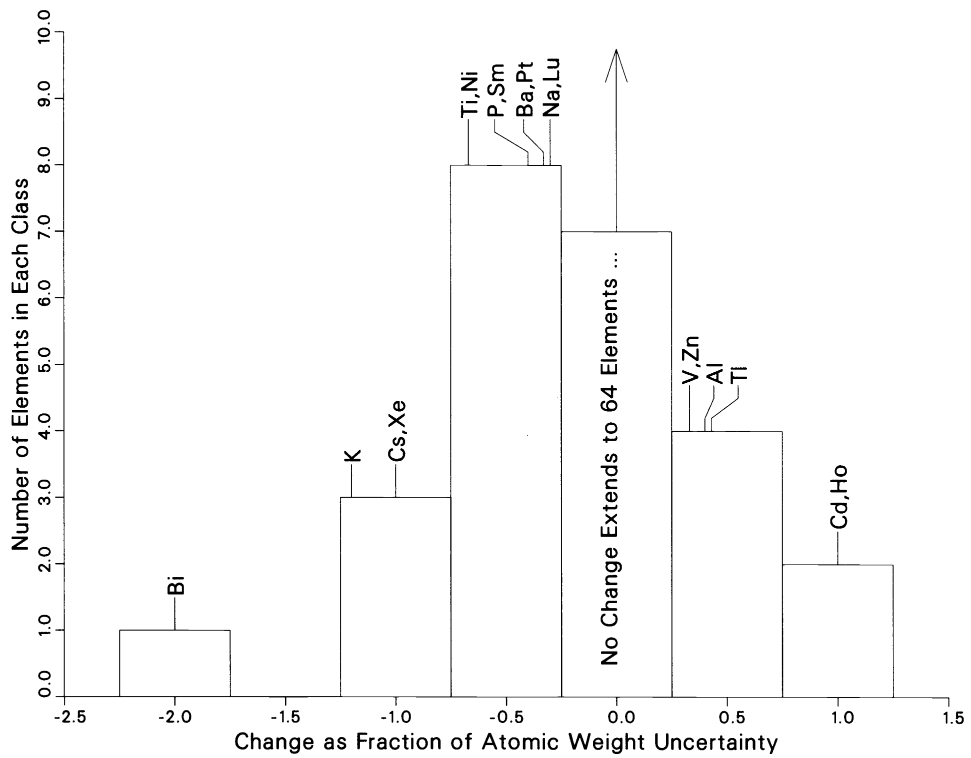


Figure 2. Histogram of Magnitude of Changes in Atomic Weight Values from 1969-1981.

The biggest changes on an absolute atomic weight scale have been made for Sm followed by Ti, Ni, and Pd. For Sm and Pd they were well anticipated by the difficulties to which chemists were subjected in the purification of these elements. Future adjustments are likely to be much smaller. As already mentioned, the Commission is not as sanguine about Ti, although it can take some satisfaction that it correctly interpreted the lack of reliability of the work on which its atomic weight was and continues to be based.

Relative to their relevant atomic weights, the changes made to the values since 1969 are largest for Ti, Ni, Sm, Pd, and Zn in that order. Of these, Ti, Ni, and Zn may possibly undergo further similar adjustments. The variability in normal sources for them is likely to be much smaller than the experimental uncertainty of their present values.

The pressing need for new and more precise determinations of atomic weight is highlighted by the above discussion. The Commission is concerned that atomic weight determinations using calibrated isotopes will not be possible since these isotopes may become unavailable for the foreseeable future. In view of this circumstance the Commission wishes to encourage mass-spectrometric measurements with elements like zinc employing the double-spike technique which is more accurate than a non-calibrated measurement. The Commission notes that the new determination of the atomic weight of silver referred to in the last Report has been completed and that work is underway on the atomic weights of gallium, nickel, lithium and neodymium.

TABLE OF ATOMIC WEIGHTS TO FIVE SIGNIFICANT FIGURES

The Commission has reaffirmed its basic function which is to disseminate the most accurate information on atomic weights currently available. It does not seek to judge that the sixth, seventh, or any significant figure can never be of interest to any user of the Table of Standard Atomic Weights. If published work leads to an atomic weight that is thought by the Commission to be reliable and more precise than the value previously tabulated, or if evidence becomes available for the introduction of an important annotation, a change in the Table is made. Thus, the details of the Table in many respects exceed the needs of many users who are more concerned with increasing the length of time during which a given Table has full validity. The Commission has, therefore, decided to publish a table of atomic weights abbreviated to five figures (or fewer where uncertainties do not warrant even five-figure accuracy). This Table 4 is given with the reasonable hope that the quoted values will not need to be changed for several years at least, a desirable attribute for use in textbooks and other numerical tables derived from atomic weight data.

TABLE 4. Atomic Weights to Five Significant Figures

(Scaled to the relative atomic mass, $\underline{A}_r(^{12}C) = 12$)

Atomic weights are quoted to five significant figures unless the dependable precision is more limited by one or more of the following:

i. the combined uncertainties of the best published atomic-weight determinations:

ii. variability in normal terrestrial materials (footnote r); and

iii. existence in quantity of materials that have suffered undisclosed or inadvertent isotopic separation (footnote m).

The last significant figure in the Table is considered reliable to ±1, or less, except when marked ±3 to indicate that larger uncertainty. Ignored in this Table are highly abnormal isotopic compositions in rare geological occurences that are most unlikely to become source materials for chemical laboratories or industrial applications. The tabulated values do not generally apply to enriched or separated isotopes or to materials the isotopic composition of which has been deliberately altered. Radioactive elements that lack a characteristic terrestrial isotopic composition to 5-figure accuracy are represented by one or more well-known isotopes identified in the Table by their mass number in superscript preceding the chemical symbol. Users should refer to the full Table of Standard Atomic Weights for the sources of the data and more detailed information.

Atomic Number	Name	Symbol	Atomic Weight	Footnotes	
1	Hydrogen	H	1.0079		
2	Helium	He	4.0026		
3	Lithium	Li	6.941 ± 3	m	r
4	Beryllium	Be	9.0122		
5	Boron	B	10.81	m	r
6	Carbon	C	12.011		
7	Nitrogen	N	14.007		
8	Oxygen	O	15.999		
9	Fluorine	F	18.998		
10	Neon	Ne	20.179	m	
11	Sodium (Natrium)	Na	22.990		
12	Magnesium	Mg	24.305		
13	Aluminium	Al	26.982		
14	Silicon	Si	28.086		
15	Phosphorus	P	30.974		
16	Sulfur	S	32.06		r
17	Chlorine	Cl	35.453		
18	Argon	Ar	39.948		
19	Potassium (Kalium)	K	39.098		
20	Calcium	Ca	40.08		
21	Scandium	Sc	44.956		
22	Titanium	Ti	47.88 ± 3		
23	Vanadium	V	50.942		
24	Chromium	Cr	51.996		
25	Manganese	Mn	54.938		
26	Iron	Fe	55.847 ± 3		
27	Cobalt	Co	58.933		
28	Nickel	Ni	58.69		
29	Copper	Cu	63.546 ± 3		
30	Zinc	Zn	65.38		
31	Gallium	Ga	69.72		
32	Germanium	Ge	72.59 ± 3		
33	Arsenic	As	74.922		
34	Selenium	Se	78.96 ± 3		
35	Bromine	Br	79.904		
36	Krypton	Kr	83.80	m	
37	Rubidium	Rb	85.468		
38	Strontium	Sr	87.62		
39	Yttrium	Y	88.906		
40	Zirconium	Zr	91.22		
41	Niobium	Nb	92.906		
42	Molybdenum	Mo	95.94		
43	Technetium*	^{97}Tc	96.906		
		^{98}Tc	97.907		

TABLE 4. Atomic Weights to Five Significant Figures (cont'd)

Atomic Number	Name	Symbol	Atomic Weight	Footnotes
		^{99}Tc	98.906	
44	Ruthenium	Ru	101.07 ± 3	
45	Rhodium	Rh	102.91	
46	Palladium	Pd	106.42	
47	Silver	Ag	107.87	
48	Cadmium	Cd	112.41	
49	Indium	In	114.82	
50	Tin	Sn	118.69 ± 3	
51	Antimony (Stibium)	Sb	121.75 ± 3	
52	Tellurium	Te	127.60 ± 3	
53	Iodine	I	126.90	
54	Xenon	Xe	131.29 ± 3	m
55	Caesium	Cs	132.91	
56	Barium	Ba	137.33	
57	Lanthanum	La	138.91	
58	Cerium	Ce	140.12	
59	Praseodymium	Pr	140.91	
60	Neodymium	Nd	144.24 ± 3	
61	Promethium*	^{145}Pm	144.91	
62	Samarium	Sm	150.36 ± 3	
63	Europium	Eu	151.96	
64	Gadolinium	Gd	157.25 ± 3	
65	Terbium	Tb	158.93	
66	Dysprosium	Dy	162.50 ± 3	
67	Holmium	Ho	164.93	
68	Erbium	Er	167.26 ± 3	
69	Thulium	Tm	168.93	
70	Ytterbium	Yb	173.04 ± 3	
71	Lutetium	Lu	174.97	
72	Hafnium	Hf	178.49 ± 3	
73	Tantalum	Ta	180.95	
74	Wolfram (Tungsten)	W	183.85 ± 3	
75	Rhenium	Re	186.21	
76	Osmium	Os	190.2	
77	Iridium	Ir	192.22 ± 3	
78	Platinum	Pt	195.08 ± 3	
79	Gold	Au	196.97	
80	Mercury	Hg	200.59 ± 3	
81	Thallium	Tl	204.38	
82	Lead	Pb	207.2	r
83	Bismuth	Bi	208.98	
84	Polonium*	^{209}Po	208.98	
		^{210}Po	209.98	
85	Astatine*	^{210}At	209.99	
86	Radon*	^{211}Rn	210.99	
		^{222}Rn	222.02	
87	Francium*	^{223}Fr	223.02	
88	Radium*	^{226}Ra	226.03	
		^{228}Ra	228.03	
89	Actinium*	^{227}Ac	227.03	
90	Thorium*	^{230}Th	230.03	
		^{232}Th	232.04	
91	Protactinium*	^{231}Pa	231.04	
92	Uranium*	U	238.03	
93	Neptunium*	^{237}Np	237.05	
		^{239}Np	239.05	
94	Plutonium*	^{238}Pu	238.05	
		^{239}Pu	239.05	
		^{244}Pu	244.06	
95	Americium*	^{241}Am	241.06	
		^{243}Am	243.06	
96	Curium*	^{247}Cm	247.07	
		^{248}Cm	248.08	
97	Berkelium*	^{247}Bk	247.07	
98	Californium*	^{251}Cf	251.08	
		^{252}Cf	252.08	
99	Einsteinium*	^{252}Es	252.08	

TABLE 4. Atomic Weights to Five Significant Figures (cont'd)

Atomic Number	Name	Symbol	Atomic Weight	Footnotes
100	Fermium*	^{257}Fm	257.10	
101	Mendelevium*	^{256}Md	256.09	
		^{258}Md	258.10	
102	Nobelium*	^{259}No	259.10	
103	Lawrencium*	^{260}Lr	260.11	

m Modified isotopic compositions may be found in commercially available material causing deviations of the atomic weight value from that given in the Table because the material has been subjected to an undisclosed or inadvertent isotopic separation.

r Range in isotopic composition in normal terrestrial materials limits the precision in the tabulated value of the atomic weight.

* Element has no stable isotopes. Uranium is the only such element which has a characteristic terrestrial composition of long-lived isotopes with an atomic weight which to 5-figure accuracy differs from the relative atomic mass of one of its isotopes.

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

For many years the Commission has included in its Report a Table of Relative Atomic Masses and Half-Lives of Selected Radionuclides, even though it has no prime responsibility for the dissemination of such values. No attempt has, therefore, been made to state these values at the best precision possible or to make them any more complete than is needed to enable users to calculate the atomic weights of materials of abnormal or changing isotopic composition. In this year's Table 5 the values are again those recommended by A.H. Wapstra (Ref. 14) and the half-lives were provided by N.E. Holden (Ref. 15). The latest atomic-mass data were surveyed and no significant changes have resulted.

ISOTOPIC ABUNDANCE VARIATION DUE TO MAGNETIC EFFECTS

The Commission considered the problem of anomalous variations in the isotopic abundance of elements resulting from the difference of magnetic moments of isotopes involved in free radical reactions. Work published during the past five years (Refs. 16-19) has described chemical-magnetic effects which can lead to the isotopic enrichment or depletion of various products of those chemical reactions, both in the solid and liquid state, which proceed with the participation of free radicals. The Commission is of the view that, although the isotopic composition might be slightly changed, especially in the manufacture of some pharmaceutical chemicals, the chemical magnetic effect will not be detectable in most commercially available materials. This is likely to remain true for the immediate future.

NON-TERRESTRIAL DATA

The isotopic abundances of elements from non-terrestrial sources form a rich and rapidly expanding body of information. Extensive searches for differences in isotopic composition between terrestrial and non-terrestrial materials have been carried out in meteorites and lunar samples, and it has now been estabished that isotopic anomalies exist in a number of gaseous and non-gaseous elements. Information about non-terrestrial isotopic abundances can come from meteoritic and lunar materials, from space probes, from astronomical observations or from cosmic rays. Although this Commission does not attempt to review systematically the literature on the isotopic composition of extra-terrestrial materials, a number of elements were listed in its 1979 Report (Ref. 1), in which variations in isotopic composition from terrestrial values have been reported.

These anomalies may have been produced by mass fractionation, nuclear reactions or by solar wind implantation, with often more than one process involved in a given sample. Mass dependent fractionation (e.g., diffusion, chemical reactions, etc.), may have occurred both before and after solar system formation. The category of nuclear reactions include anomalies which may be produced from nucleosynthetic processes, by spallation reactions caused by cosmic ray bombardment, by low energy neutron irradiation or from radioactive decay of extinct radionuclides (e.g., ^{26}Al, ^{107}Pd) or as a result of fission. Solar wind implantation has altered the isotopic composition of a number of elements in lunar and meteoritic samples. Excellent reviews describing isotopic anomalies in non-terrestrial materials are given by Begemann (Ref. 20) and Wasserburg *et al.* (Ref. 21).

TABLE 5. Relative Atomic Masses and Half-Lives of Selected Radionuclides

Name	Symbol	Atomic number	Mass number	Relative Atomic mass	Half-Life	+
Technetium	Tc	43	97	96.906	2.6x10^{6}	a
			98	97.907	4.2x10^{6}	a
			99	98.906	2.13x10^{5}	a
Promethium	Pm	61	145	144.913	18.	a
			147	146.915	2.62	a
Polonium	Po	84	208	207.981	2.90	a
			209	208.982	102.	a
			210	209.983	138.38	d
Astatine	At	85	209	208.986	5.4	h
			210	209.987	8.1	h
			211	210.987	7.21	h
Radon	Rn	86	211	210.991	14.6	h
			222	222.018	3.824	d
Francium	Fr	87	212	211.996	19.3	m
			222	222.018	15.	m
			223	223.020	22.	m
Radium	Ra	88	226	226.025	1600.	a
			228	228.031	5.75	a
Actinium	Ac	89	225	225.023	10.0	d
			227	227.028	21.77	a
Thorium	Th	90	230	230.033	7.7x10^{4}	a
			232	232.038	1.40x10^{10}	a
Protactinium	Pa	91	230	230.035	17.4	d
			231	231.036	3.28x10^{4}	a
			233	233.040	27.0	d
Uranium	U	92	233	233.040	1.59x10^{5}	a
			234	234.041	2.45x10^{5}	a
			235	235.044	7.04x10^{8}	a
			236	236.046	2.34x10^{7}	a
			238	238.051	4.47x10^{9}	a
Neptunium	Np	93	236	236.047	1.1x10^{5}	a
			237	237.048	2.14x10^{6}	a
Plutonium	Pu	94	238	238.050	87.7	a
			239	239.052	2.41x10^{4}	a
			240	240.054	6.54x10^{3}	a
			241	241.057	14.4	a
			242	242.059	3.8x10^{5}	a
			244	244.064	8.3x10^{7}	a
Americium	Am	95	241	241.057	4.32x10^{2}	a
			243	243.061	7.37x10^{3}	a
Curium	Cm	96	242	242.059	163.	d
			243	243.061	28.5	a
			244	244.063	18.1	a
			245	245.065	8.5x10^{3}	a
			246	246.067	4.71x10^{3}	a
			247	247.070	1.55x10^{7}	a
			248	248.072	3.5x10^{5}	a
			250	250.078	8.x10^{3}	a
Berkelium	Bk	97	247	247.070	1.4x10^{3}	a
			249	249.075	3.2x10^{2}	d

TABLE 5. Relative Atomic Masses and Half-Lives of Selected Radionuclides (cont'd)

Name	Symbol	Atomic number	Mass number	Relative Atomic mass	Half-Life	+
Californium	Cf	98	248	248.072	334.	d
			249	249.075	$3.51\text{x}10^2$	a
			251	251.080	$9.0\text{x}10^2$	a
			252	252.082	2.65	a
			254	254.087	6.x10	d
Einsteinium	Es	99	252	252.083	472.	d
			253	253.085	20.47	d
			254	254.088	276.	d
Fermium	Fm	100	255	255.090	20.1	h
			257	257.095	100.5	d

+a=year; d=day; h=hour; m=minute.

Several new methods for the study of isotopic abundance on non-terrestrial samples have been developed recently. For the past several years, spectroscopic experiments using light emitted from excited atoms in non-terrestrial objects have been employed to infer the isotopic abundance of the group of emitting atoms. Another new source of information involves cosmic ray measurements. Identification experiments for individual cosmic ray particles have improved to such an extent in the past several years that measurements of Z and A can be made to a small fraction of a mass unit. Thus, one can begin to speak of the isotopic abundance for a particular element in the cosmic rays as an experimentally determined quantity. In this type of experiment, detectors in the form of nuclear emulsions or particle counter arrays are employed to measure energy loss and total energy which in turn can be related to Z and A of the cosmic ray particle. Both optical and cosmic ray experiments reveal significant variations in isotopic abundance data for material from outside the solar system. For example, there is strong evidence that neutron-rich isotopes of neon, magnesium, and silicon are more abundant than in terrestrial material. An excellent review article describing both spectroscopic and cosmic ray results has been written by Wannier (Ref. 22). Details about cosmic ray abundance measurements can be found in Mewaldt _et al_. (Ref. 23).

Although most of the reported isotopic variations in non-terrestrial samples are small and thus will cause only small changes in the atomic weight of the material, there are a number of variations that are quite large. For this reason, chemists dealing with non-terrestrial samples should exercise caution when the atomic weight or the isotopic abundance of a non-terrestrial sample is required.

OTHER PROJECTS OF THE COMMISSION

The Commission remains concerned that a variety of chemicals are available from commercial and other sources containing elements with an abnormal isotopic composition due to inadvertent or undisclosed enrichment or depletion. This problem has been discussed in detail in successive Reports since 1973 and the Commission urges manufacturers to follow its recommendations for labelling well-characterized chemicals which are set out in the 1979 Report (Ref. 1).

The Commission has decided to revise the Table of Atomic Weights to Four Significant Figures which was prepared originally for the IUPAC Committee on Teaching of Chemistry and published in their "International Newsletter on Chemical Education" (Ref. 24). This simplified Table is designed for students and teachers. It introduces them to the fact that not all atomic weights are constants of nature even at the precision of their concern. The $\underline{A_r}(E)$ values quoted to four significant figures are unlikely to require alteration in subsequent revisions.

The Subcommittee for the Assessment of Isotopic Composition (SAIC) within the Commission on Atomic Weights and Isotopic Abundances is continuing its element-by-element review of all measurements for deriving isotopic compositions with the objective of arriving at best values which are consistent with the Table of Standard Atomic Weights. Present members of SAIC are P. de Bièvre (Chairman), I.L. Barnes, R. Hagemann, N.E. Holden, J.R. de Laeter, T.J. Murphy, H.S. Peiser and H.G. Thode.

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