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COMMISSION ON ATOMIC WEIGHTS AND ISOTOPIC ABUNDANCES*

ATOMIC WEIGHTS OF THE ELEMENTS 1997

(Technical Report)

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Dedicated to H.S. Peiser on the occasion of his 80th birthday

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Atomic weights of the elements 1997 (Technical Report)

Abstract: The biennial review of atomic weight determinations, $A_r(E)$, and other cognate data has warranted no changes for the standard atomic weights of the elements from that previously published in the Table of Atomic Weights 1995 with the exception of a new footnote for lithium. The names for the transfermium elements with atomic numbers 101–109 have been officially adopted, and element 112 has been synthesized. Many elements in nonterrestrial matter have isotopic compositions different from those in similar terrestrial substances that may affect their atomic weight. Some recent isotopic data on xenon and oxygen in nonterrestrial materials are included in this report together with a discussion of the possible processes causing these changes.

INTRODUCTION

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Professor L. Schultz from 24 to 26 August 1997, during the 39th IUPAC General Assembly in Geneva, Switzerland. The Commission decided to publish the report 'Atomic Weights of the Elements 1997' as presented here and the report 'Isotopic Compositions of the Elements 1997' [1].

The Commission has reviewed the literature over the previous two years since the last report on atomic weights and evaluated the published data on atomic weights and isotopic compositions on an element-by-element basis. The atomic weight, $A_r(E)$, of element E can be determined from a knowledge of the isotopic abundances and corresponding atomic masses of the nuclides of that element [2]. The last compilations of the isotopic abundances and atomic masses with all relevant data were published in 1998 [1]. The Commission periodically reviews the history of the atomic weight of each element emphasizing the relevant published scientific evidence on which decisions have been made [3]. The biennial review of atomic weight determinations, $A_r(E)$, and other cognate data has warranted no changes for the standard atomic weights of the elements from that previously published in the Table of Atomic Weights 1995 [4] with the exception of a new footnote for lithium.

COMMENTS ON SOME ATOMIC WEIGHTS AND FOOTNOTES

Lithium

The Commission has changed the footnote for lithium in the Table of Atomic Weights to: 'Commercially available Li materials have atomic weights that are known to range from 6.939 to 6.996; if a more accurate value is required, it must be determined for the specific material'. The increase in the range of atomic weights is based on a published report [5] which evaluated the variation in isotopic abundance of commercially available lithium reagents and documented an extreme range in isotopic variations and consequent effects on atomic weights. The Commission felt that the modification of the footnote was warranted to warn users that isotopically anomalous commercial lithium reagents were available whose atomic weights fell well outside the implied range of the atomic weight for lithium.

Transfermium elements

The IUPAC Commission on Nomenclature of Inorganic Chemistry (CNIC) has revised their recommendations for the names and symbols of the transfermium elements (atomic numbers 101–109 inclusive) and these recommendations have been adopted [6]. All atomic weight tables have been modified to reflect this new nomenclature.

Element 112 (Ununbiium)

A new element with atomic number 112 has been synthesized and unambiguously identified [7] by an international group of researchers at the Gesellschaft für Schwerionenforschung, Darmstadt, Germany. As an official name has not yet been adopted, the systematic name and symbol (Ununbiium, Uub, respectively) as specified by the CNIC, have been used in the following Tables of Atomic Weights.

THE TABLE OF STANDARD ATOMIC WEIGHTS 1997

Following past practice, the Table of Standard Atomic Weights 1997 is presented both in alphabetical order by names in English of the elements (Table 1) and in order of atomic numbers (Table 2).

Table 1 Standard atomic weights 1997—alphabetical order in English (scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state). The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$. Names of elements with atomic numbers 110, 111 and 112 are temporary.

Name	Atomic symbol	Atomic number	Weight	Footnotes
Actinium*	Ac	89		
Aluminium (Aluminum)	Al	13	26.981538(2)	
Americium*	Am	95		
Antimony (Stibium)	Sb	51	121.760(1)	g
Argon	Ar	18	39.948(1)	g r
Arsenic	As	33	74.92160(2)	
Astatine*	At	85		
Barium	Ba	56	137.327(7)	
Berkelium*	Bk	97		
Beryllium	Be	4	9.012182(3)	
Bismuth	Bi	83	208.98038(2)	
Bohrium*	Bh	107		
Boron	B	5	10.811(7)	g m r
Bromine	Br	35	79.904(1)	
Cadmium	Cd	48	112.411(8)	g
Caesium (Caesium)	Cs	55	132.90545(2)	
Calcium	Ca	20	40.078(4)	g
Californium*	Cf	98		
Carbon	C	6	12.0107(8)	g r
Cerium	Ce	58	140.116(1)	g
Chlorine	Cl	17	35.4527(9)	m
Chromium	Cr	24	51.9961(6)	
Cobalt	Co	27	58.933200(9)	
Copper	Cu	29	63.546(3)	r
Curium*	Cm	96		
Dubnium*	Db	105		
Dysprosium	Dy	66	162.50(3)	g
Einsteinium*	Es	99		
Erbium	Er	68	167.26(3)	g
Europium	Eu	63	151.964(1)	g
Fermium*	Fm	100		
Fluorine	F	9	18.9984032(5)	
Francium*	Fr	87		
Gadolinium	Gd	64	157.25(3)	g
Gallium	Ga	31	69.723(1)	

Table 1 *Continued*

Germanium	Ge	32	72.61(2)			
Gold	Au	79	196.96655(2)			
Hafnium	Hf	72	178.49(2)			
Hassium*	Hs	108				
Helium	He	2	4.002602(2)	g		r
Holmium	Ho	67	164.93032(2)			
Hydrogen	H	1	1.00794(7)	g	m	r
Indium	In	49	114.818(3)			
Iodine	I	53	126.90447(3)			
Iridium	Ir	77	192.217(3)			
Iron	Fe	26	55.845(2)			
Krypton	Kr	36	83.80(1)	g	m	
Lanthanum	La	57	138.9055(2)	g		
Lawrencium*	Lr	103				
Lead	Pb	82	207.2(1)	g		r
Lithium	Li	3	$(6.941(2))^{+}$	g	m	r
Lutetium	Lu	71	174.967(1)	g		
Magnesium	Mg	12	24.3050(6)			
Manganese	Mn	25	54.938049(9)			
Meitnerium*	Mt	109				
Mendelevium*	Md	101				
Mercury	Hg	80	200.59(2)			
Molybdenum	Mo	42	95.94(1)	g		
Neodymium	Nd	60	144.24(3)	g		
Neon	Ne	10	20.1797(6)	g	m	
Neptunium*	Np	93				
Nickel	Ni	28	58.6934(2)			
Niobium	Nb	41	92.90638(2)			
Nitrogen	N	7	14.00674(7)	g		r
Nobelium*	No	102				
Osmium	Os	76	190.23(3)	g		
Oxygen	O	8	15.9994(3)	g		r
Palladium	Pd	46	106.42(1)	g		
Phosphorus	P	15	30.973761(2)			
Platinum	Pt	78	195.078(2)			
Plutonium*	Pu	94				
Polonium*	Po	84				
Potassium (Kalium)	K	19	39.0983(1)			
Praseodymium	Pr	59	140.90765(2)			
Promethium*	Pm	61				
Protactinium*	Pa	91	231.03588(2)			
Radium*	Ra	88				
Radon*	Rn	86				
Rhenium	Re	75	186.207(1)			
Rhodium	Rh	45	102.90550(2)			
Rubidium	Rb	37	85.4678(3)	g		
Ruthenium	Ru	44	101.07(2)	g		
Rutherfordium*	Rf	104				
Samarium	Sm	62	150.36(3)	g		
Scandium	Sc	21	44.955910(8)			
Seaborgium*	Sg	106				
Selenium	Se	34	78.96(3)			
Silicon	Si	14	28.0855(3)			r
Silver	Ag	47	107.8682(2)	g		
Sodium (Natrium)	Na	11	22.989770(2)			
Strontium	Sr	38	87.62(1)	g		r
Sulfur	S	16	32.066(6)	g		r

Table 1 *Continued*

Tantalum	Ta	73	180.9479(1)		
Technetium*	Tc	43			
Tellurium	Te	52	127.60(3)	g	
Terbium	Tb	65	158.92534(2)		
Thallium	Tl	81	204.3833(2)		
Thorium*	Th	90	232.0381(1)	g	
Thulium	Tm	69	168.93421(2)		
Tin	Sn	50	118.710(7)	g	
Titanium	Ti	22	47.867(1)		
Tungsten (Wolfram)	W	74	183.84(1)		
Ununnilium*	Uun	110			
Unununium*	Uuu	111			
Ununbiium*	Uub	112			
Uranium*	U	92	238.0289(1)	g	m
Vanadium	V	23	50.9415(1)		
Xenon	Xe	54	131.29(2)	g	m
Ytterbium	Yb	70	173.04(3)	g	
Yttrium	Y	39	88.90585(2)		
Zinc	Zn	30	65.39(2)		
Zirconium	Zr	40	91.224(2)	g	

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

$^{+}$Commercially available Li materials have atomic weights that are known to range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

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

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

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

The atomic weights reported in Tables 1 and 2 are for atoms in their electronic and nuclear ground states. The unified atomic mass unit (u) is equal to 1/12 of the rest mass of the neutral atom of ^{12}C in its nuclear and electronic ground state.

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

The names and symbols for the elements with atomic numbers 110, 111 and 112 referred to in the tables are systematic and based on the atomic numbers of the elements recommended for temporary use by the CNIC [8]. The names are composed of the following roots representing each digit of the atomic number:

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

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

For atomic weight values, the uncertainties are routinely called ‘expanded uncertainties’ with the symbol U in italic font. The symbol $U(A_r(E))$ is an acceptable alternative to U. In past reports, the Commission has referred to relative uncertainty which is the magnitude of the uncertainty divided by

Table 2 Standard atomic weights 1997—order of atomic number (scaled to $A_r(^{12}C) = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state). The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The standard values of $A_r(E)$ and the uncertainties (in parentheses, following the last significant figure to which they are attributed) apply to elements of natural terrestrial origin. The footnotes to this Table elaborate the types of variation which may occur for individual elements and which may be larger than the listed uncertainties of values of $A_r(E)$. Names of elements with atomic number 110, 111 and 112 are temporary

Atomic number	Name	Atomic symbol	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(7)	g m r
6	Carbon	C	12.0107(8)	g r
7	Nitrogen	N	14.00674(7)	g r
8	Oxygen	O	15.9994(3)	g r
9	Fluorine	F	18.9984032(5)	
10	Neon	Ne	20.1797(6)	g m
11	Sodium (Natrium)	Na	22.989770(2)	
12	Magnesium	Mg	24.3050(6)	
13	Aluminium (Aluminum)	Al	26.981538(2)	
14	Silicon	Si	28.0855(3)	r
15	Phosphorus	P	30.973761(2)	
16	Sulfur	S	32.066(6)	g r
17	Chlorine	Cl	35.4527(9)	m
18	Argon	Ar	39.948(1)	g r
19	Potassium (Kalium)	K	39.0983(1)	
20	Calcium	Ca	40.078(4)	g
21	Scandium	Sc	44.955910(8)	
22	Titanium	Ti	47.867(1)	
23	Vanadium	V	50.9415(1)	
24	Chromium	Cr	51.9961(6)	
25	Manganese	Mn	54.938049(9)	
26	Iron	Fe	55.845(2)	
27	Cobalt	Co	58.933200(9)	
28	Nickel	Ni	58.6934(2)	
29	Copper	Cu	63.546(3)	r
30	Zinc	Zn	65.39(2)	
31	Gallium	Ga	69.723(1)	
32	Germanium	Ge	72.61(2)	
33	Arsenic	As	74.92160(2)	
34	Selenium	Se	78.96(3)	
35	Bromine	Br	79.904(1)	
36	Krypton	Kr	83.80(1)	g m
37	Rubidium	Rb	85.4678(3)	g
38	Strontium	Sr	87.62(1)	g r
39	Yttrium	Y	88.90585(2)	
40	Zirconium	Zr	91.224(2)	g
41	Niobium	Nb	92.90638(2)	
42	Molybdenum	Mo	95.94(1)	g
43	Technetium*	Tc		
44	Ruthenium	Ru	101.07(2)	g
45	Rhodium	Rh	102.90550(2)	
46	Palladium	Pd	106.42(1)	g
47	Silver	Ag	107.8682(2)	g
48	Cadmium	Cd	112.411(8)	g

Table 2 *Continued*

49	Indium	In	114.818(3)			
50	Tin	Sn	118.710(7)	g		
51	Antimony (Stibium)	Sb	121.760(1)	g		
52	Tellurium	Te	127.60(3)	g		
53	Iodine	I	126.90447(3)			
54	Xenon	Xe	131.29(2)	g	m	
55	Caesium (Caesium)	Cs	132.90545(2)			
56	Barium	Ba	137.327(7)			
57	Lanthanum	La	138.9055(2)	g		
58	Cerium	Ce	140.116(1)	g		
59	Praseodymium	Pr	140.90765(2)			
60	Neodymium	Nd	144.24(3)	g		
61	Promethium*	Pm				
62	Samarium	Sm	150.36(3)	g		
63	Europium	Eu	151.964(1)	g		
64	Gadolinium	Gd	157.25(3)	g		
65	Terbium	Tb	158.92534(2)			
66	Dysprosium	Dy	162.50(3)	g		
67	Holmium	Ho	164.93032(2)			
68	Erbium	Er	167.26(3)	g		
69	Thulium	Tm	168.93421(2)			
70	Ytterbium	Yb	173.04(3)	g		
71	Lutetium	Lu	174.967(1)	g		
72	Hafnium	Hf	178.49(2)			
73	Tantalum	Ta	180.9479(1)			
74	Tungsten (Wolfram)	W	183.84(1)			
75	Rhenium	Re	186.207(1)			
76	Osmium	Os	190.23(3)	g		
77	Iridium	Ir	192.217(3)			
78	Platinum	Pt	195.078(2)			
79	Gold	Au	196.96655(2)			
80	Mercury	Hg	200.59(2)			
81	Thallium	Tl	204.3833(2)			
82	Lead	Pb	207.2(1)	g		r
83	Bismuth	Bi	208.98038(2)			
84	Polonium*	Po				
85	Astatine*	At				
86	Radon*	Rn				
87	Francium*	Fr				
88	Radium*	Ra				
89	Actinium*	Ac				
90	Thorium*	Th	232.0381(1)	g		
91	Protactinium*	Pa	231.03588(2)			
92	Uranium*	U	238.0289(1)	g	m	
93	Neptunium*	Np				
94	Plutonium*	Pu				
95	Americium*	Am				
96	Curium*	Cm				
97	Berkelium*	Bk				
98	Californium*	Cf				
99	Einsteinium*	Es				
100	Fermium*	Fm				
101	Mendelevium*	Md				
102	Nobelium*	No				
103	Lawrencium*	Lr				
104	Rutherfordium*	Rf				

Table 2 *Continued*

105	Dubnium*	Db
106	Seaborgium*	Sg
107	Bohrium*	Bh
108	Hassium*	Hs
109	Meitnerium*	Mt
110	Ununnilium*	Uun
111	Unununium*	Uuu
112	Ununbiium*	Uub

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

$^{+}$Commercially available Li materials have atomic weights that are known to range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

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

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

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

$A_r(E)$. Therefore, relative expanded uncertainty is indicated as $U/A_r(E)$ or alternatively as $U(A_r(E))/A_r(E)$.

Figure 1 shows the changes in the relative uncertainties, $U(A_r(E))/A_r(E)$, of the recommended standard atomic weights of the elements from 1969 to 1997. Arrowheads mark the 1997 relative uncertainties, which are the same as the 1995 uncertainties. The base of each arrow marks the position of the relative uncertainty estimate in 1969. The change factor is represented by the length of the arrow and equals the ratio of the relative uncertainty at the base to that at the tip of the arrow. The symbol ⏀ indicates no change since 1969, corresponding to an 'improvement factor' of 1; this applies to 14 elements. Only one element (Xe) has an 'improvement factor' of less than 1, indicating a loss in the estimate of relative uncertainty.

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

The Commission on Atomic Weights and Isotopic Abundances, as in previous years, publishes a table of relative atomic masses and half-lives of selected radionuclides for elements without a stable nuclide (see Table 3). As the Commission has no prime responsibility for the dissemination of such values, it has neither attempted to record the best precision possible nor to make its tabulation comprehensive. There is no general agreement on which of the isotopes of the radioactive elements is, or is likely to be judged, 'important'. Various criteria such as 'longest half-life', 'production in quantity', 'used commercially', etc., have been applied in the Commission's choice. The relative atomic masses are derived from the atomic masses (in u) recommended by Audi & Wapstra [2]. The half-lives listed are those provided by Holden [9–11].

NONTERRESTRIAL DATA

Introduction

The isotopic abundance of elements in nonterrestrial samples within the solar system can be obtained by the analysis of meteorites and interplanetary materials. Furthermore, the use of spacecraft and ground-based astronomical observatories has extended isotopic measurements from our solar system to stellar matter. Such developments have rapidly increased the number of nonterrestrial isotopic composition data in recent years.

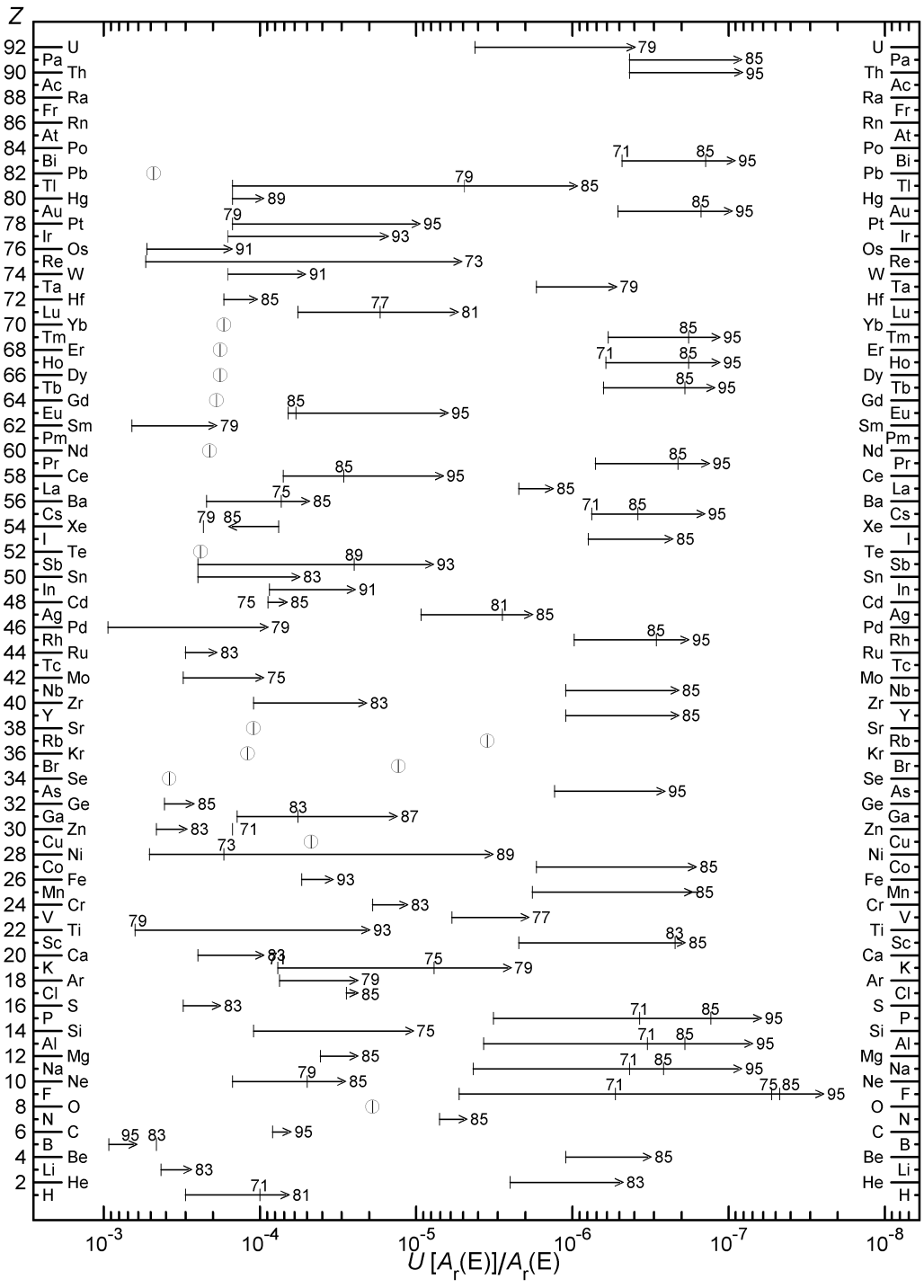

Fig. 1 Changes in the relative uncertainty, $U(A_r(E))/A_r(E)$, of the IUPAC-recommended atomic weights of the elements between 1969 and 1997 [12]. The symbol ⦶ indicates no change. Numbers, where given, are the last two digits of the year of the last change. Intermediate changes are indicated by the symbol | together with the year of the change. Details of the construction of this figure are given in the text of [3].

As a consequence of this effort at analyzing nonterrestrial materials, it is now well established that many elements in nonterrestrial materials have isotopic compositions different from those in terrestrial samples. While most reported isotopic anomalies are small, some variations are quite large and greatly exceed the range observed in terrestrial materials. For this reason, scientists dealing with chemical

Table 3 Relative atomic masses and half-lives of selected radionuclides

Atomic number	Name	Symbol	Mass number	Relative atomic mass	Half-Life and uncertainty	Unit*
43	Technetium	Tc	97	96.9064	$2.6 \pm 0.4 \times 10^6$	a
			98	97.9072	$4.2 \pm 0.3 \times 10^6$	a
			99	98.9063	$2.1 \pm 0.3 \times 10^5$	a
61	Promethium	Pm	145	144.9127	17.7 ± 0.4	a
			147	146.9151	2.623 ± 0.003	a
84	Polonium	Po	209	208.9824	102 ± 5	a
			210	209.9828	138.4 ± 0.1	d
85	Astatine	At	210	209.9871	8.1 ± 0.4	h
			211	210.9875	7.21 ± 0.01	h
86	Radon	Rn	211	210.9906	14.6 ± 0.2	h
			220	220.0114	55.6 ± 0.1	s
			222	222.0176	3.823 ± 0.004	d
87	Francium	Fr	223	223.0197	22.0 ± 0.1	min
88	Radium	Ra	223	223.0185	11.43 ± 0.01	d
			224	224.0202	3.66 ± 0.02	d
			226	226.0254	1599 ± 4	a
			228	228.0311	5.75 ± 0.03	a
89	Actinium	Ac	227	227.0277	21.77 ± 0.02	a
90	Thorium	Th	230	230.0331	$7.54 \pm 0.03 \times 10^4$	a
			232	232.0380	$1.40 \pm 0.01 \times 10^{10}$	a
91	Protactinium	Pa	231	231.0359	$3.25 \pm 0.01 \times 10^4$	a
92	Uranium	U	233	233.0396	$1.592 \pm 0.002 \times 10^5$	a
			234	234.0409	$2.455 \pm 0.006 \times 10^5$	a
			235	235.0439	$7.04 \pm 0.01 \times 10^8$	a
			236	236.0456	$2.342 \pm 0.004 \times 10^7$	a
			238	238.0508	$4.47 \pm 0.02 \times 10^9$	a
93	Neptunium	Np	237	237.0482	$2.14 \pm 0.01 \times 10^6$	a
			239	239.0529	2.355 ± 0.006	d
94	Plutonium	Pu	238	238.0496	87.7 ± 0.01	a
			239	239.0522	$2.41 \pm 0.003 \times 10^4$	a
			240	240.0538	$6.56 \pm 0.003 \times 10^3$	a
			241	241.0568	14.4 ± 0.1	a
			242	242.0587	$3.75 \pm 0.02 \times 10^5$	a
			244	244.0642	$8.00 \pm 0.09 \times 10^7$	a
95	Americium	Am	241	241.0568	432.7 ± 0.6	a
			243	243.0614	$7.37 \pm 0.2 \times 10^3$	a
96	Curium	Cm	243	243.0614	29.1 ± 0.1	a
			244	244.0627	18.1 ± 0.1	a
			245	245.0655	$8.48 \pm 0.06 \times 10^3$	a
			246	246.0672	$4.76 \pm 0.04 \times 10^3$	a
			247	247.0703	$1.56 \pm 0.05 \times 10^7$	a
			248	248.0723	$3.48 \pm 0.06 \times 10^5$	a
97	Berkelium	Bk	247	247.0703	$1.4 \pm 0.3 \times 10^3$	a
			249	249.0750	$3.20 \pm 0.06 \times 10^2$	d
98	Californium	Cf	249	249.0748	351 ± 2	a
			250	250.0764	13.1 ± 0.1	a
			251	251.0796	$9.0 \pm 0.5 \times 10^2$	a
			252	252.0816	2.64 ± 0.01	a
99	Einsteinium	Es	252	252.0830	472 ± 2	d
100	Fermium	Fm	257	257.0951	100.5 ± 0.2	d
101	Mendelevium	Md	256	256.0941	78 ± 2	min
			258	258.0984	51.5 ± 0.3	d
102	Nobelium	No	259	259.1011	58 ± 5	min

Table 3 *Continued*

103	Lawrencium	Lr	262	262.110	3.6 ± 0.3	h
104	Rutherfordium	Rf	261	261.1089	65	s
105	Dubnium	Db	262	262.1144	34 ± 5	s
106	Seaborgium	Sg	263	263.1186	0.8 ± 0.2	s
107	Bohrium	Bh	264	264.12	0.44[a]	s
108	Hassium	Hs	265	265.1306	2[a,b]	ms
109	Meitnerium	Mt	268		70[a,b]	ms
110	Ununnilium	Uun	269		0.170[a,b]	ms
111	Unununium	Uuu	272		1.5[a,b]	ms
112	Ununbiium	Uub	277		0.240[a,b]	ms

* a = year; d = day; h = hour; min = minute; s = second; ms = millisecond. Names of elements with atomic numbers 110, 111 and 112 are temporary.
[a] The uncertainties of these elements are asymmetric.
[b] The value given is determined from only a few decays.

analyses of nonterrestrial samples should exercise caution when selecting an isotopic composition or an atomic weight for an element from a nonterrestrial sample.

Processes capable of altering isotopic abundances in nonterrestrial samples

The following processes can cause the isotopic variations observed in extra-terrestrial materials:

(i) *Mass Fractionation*. While mass dependent fractionation has been observed in many terrestrial samples, its effects are generally larger in nonterrestrial samples. Mass fractionation in nonterrestrial samples is primarily due to volatilization or condensation that occurred at an early stage of the formation of our solar system. In some cases, mass fractionation may have occurred at a later period of solar system evolution, the result of chemical processes such as the formation of organic compounds.

(ii) *Nuclear Reactions*. Nuclear reactions triggered by cosmic rays can alter the isotopic composition of both nonterrestrial and terrestrial materials. Its significance in terrestrial samples is normally trivial because of effective shielding against cosmic rays. Extraterrestrial materials, on the other hand, have no shielding and consequently show pronounced effects from solar and galactic cosmic ray bombardment.

(iii) *Radioactive Decay*.

While radioactive decay is also not limited to nonterrestrial samples, its effects are revealed by both the degree of change in isotopic abundances and in the variety of radionuclides. Enrichment in decay products is the most common effect. This enrichment is caused by long-lived radioactive nuclides whose half-lives are comparable to the age of the solar system (4.56×10^9 years). Such radionuclides are commonly used for geochronology and cosmochronology.

The next most commonly observed effects are due to extinct radionuclides. These are radionuclides with short half-lives that were once present in the solar system and have completely decayed away. All that remains are their decay products. The half-lives of such radionuclides give a measure of the period from the effective end of nucleosynthesis to the isolation of solar system materials from the surrounding gas (formation interval).

Some minor effects have also been observed in nonterrestrial samples, such as those caused by double β-decay of long-lived radionuclides and nuclear fission (both spontaneous and neutron-induced).

(iv) *Nucleosynthesis*. The most significant isotopic effects observed in materials such as meteorites are due to nucleosynthesis. Before secondary ion mass spectrometry (SIMS) measurements became available, nucleosynthetic isotopic effects had been documented in only a few peculiar mineral separates taken from meteorites. Quite a few elements within these minerals showed isotopic abundance anomalies best explained by nucleosynthetic processes during a supernova event. In particular, light elements such

as oxygen and the noble gases showed ubiquitous isotopic anomalies. SIMS measurements have confirmed that a large amount of extra-solar materials have survived in meteorites and generally show very large isotopic variations that are believed to be the result of nucleosynthesis. Some examples have been listed in the previously published *Atomic Weights of the Elements 1995* [4].

Examples of variations in isotopic abundance and atomic weights in nonterrestrial materials

Figure 2 illustrates how the aforementioned processes can alter isotopic compositions. The isotopic composition of Xe, represented by the isotopic abundance ratios $^{124}Xe/^{130}Xe$ and $^{136}Xe/^{130}Xe$, is different for different planetary reservoirs (solar, air, AVCC = average carbonaceous chondrites). The solid trend lines show the direction of expected isotopic changes from a given process. The origin of the isotopic signature of xenon from meteoritic samples (represented by open circles) suggests an admixture of nuclear reactions (including both spallation reactions caused by cosmic-rays and fission reactions) and mass fractionation. Data collected from carbonaceous chondrites suggest the presence of another Xe component that can not be explained by any of the above processes [13].

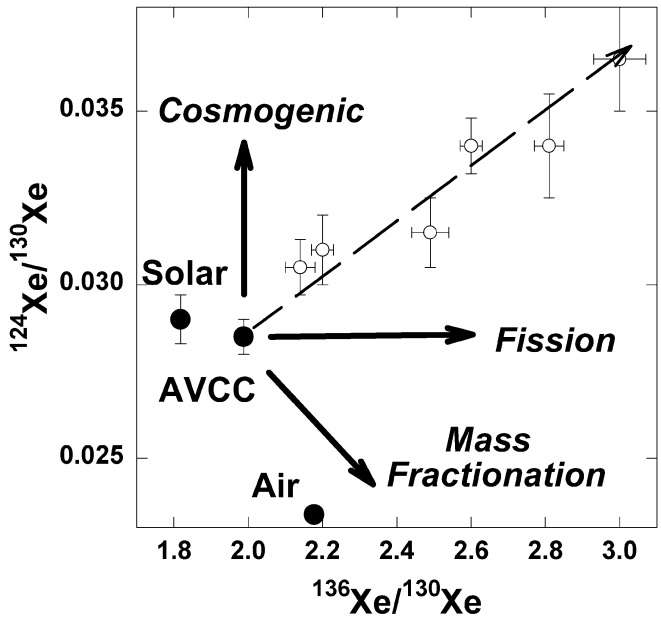

Fig. 2 The isotopic composition of xenon in selected planetary reservoirs (Solar, Air, AVCC = average carbonaceous chondrites). The solid trend lines represent various isotope fractionation processes. The dashed line passes through data from selected carbonaceous chondrites. See the text for discussion.

The isotopic composition of oxygen in the planetary bodies of our solar system is also not uniform. Different meteorite classes have their own characteristic isotopic compositions, suggesting that oxygen isotopes were not homogeneously distributed when the solar system formed. Some examples of measurements of isotopic compositions of oxygen in solar system bodies as well as astronomical objects and other matter are listed in Table 4. For comparison, values for the best measurement of representative terrestrial materials (VSMOW, a reference water) are listed as well as the representative isotopic composition from which the atomic weight of oxygen is calculated.

The commission does not attempt to systematically review the literature on the isotopic compositions of nonterrestrial materials in this report. Those who are interested in a more comprehensive review, including specific data and additional references, should refer to Shima [14] and Shima & Ebihara [15]. A more detailed report of isotopic measurements published during the last decade is in preparation.

Table 4 Examples of isotopic compositions and corresponding atomic weights of oxygen in extraterrestrial materials

Source	$\delta^{17}O/^{16}O$ (per mill)	$^{16}O/^{17}O$	$\delta^{18}O/^{16}O$ (per mill)	$^{16}O/^{18}O$	Atomic weight	Method	Refs
Meteorites (bulk)							
CI (Orgueil)	10.15		9.26		15.9994	gas MS	[16]
CR (Rumuruti)	5.52		5.07		15.9993	gas MS	[17]
CO (Ornams)	−5.34		−1.71		15.9993	gas MS	[18]
Meteorites (presolar grain)							
Al_2O_3 (Bishunpur)		385		853	16.00	SIMS	[19]
Graphite (Murchison)		3684		39	16.05	SIMS	[20]
SiC		1902		274	16.00	SIMS	[21]
Micrometeorites							
B154-B3#31 (enstatite)	−20.9		−35.7		16.00	SIMS	[22]
Interplanetary dust particles (IDP's)							
W7017 1A55	−41.2		−37.1		16.00	SIMS	[23]
Deep sea spherules							
KK1–83A	24.28		47.1		15.9995	gas MS	[24]
Lunar samples							
60015,58 glass (Apollo 16)	2.97		5.55		15.9993	gas MS	[25]
Lunar meteorite	3.03		5.64		15.9993	gas MS	[26]
Mars							
Rocks (SNC meteorites)		2673		496.3	15.9993	gas MS	[18]
Atmosphere				500		Spacecraft (Viking 2)	[27]
Sun							
Solar energetic particle		>417		526		Spacecraft	[28]
Venus							
				500		Telescope	[29]
				500		Spacecraft (Pioneer V)	[30]
Comet Halley							
H_2O				493		Spacecraft (Giotto)	[31]
Star							
α Ori (super giant)		525		700	16.0	IR Spec(CO)	[32]
β And (red giant)		155		425	16.0	IR Spec(CO)	[33]
Galactic cosmic rays							
≈0.1–0.3 GeV/amu		59		53	16.0	Spacecraft (ISEE-3)	[34]
VSMOW		2682		498.7	15.9993	gas MS	[35]
IUPAC		2625		487	15.9994		[1]

OTHER PROJECTS OF THE COMMISSION

A working party was formed under the direction of J. de Laeter that will begin an element by element review of the atomic weights. The last review took place over a decade ago and, in view of the changes that have occurred to the atomic weights, it is now due for re-examination. The working party expects to have a preliminary draft of this major review available by 1999, for the next General Assembly.

The Subcommittee for Natural Isotopic Fractionation presented an updated report on natural variations in isotopic abundance, atomic weights, and standard δ-values for selected light elements. The data going into this report were used to adjust the isotope abundances of most of the 13 light elements whose atomic weights were affected by natural isotopic variations. These adjusted values appear in the *Isotopic Composition of the Elements 1997* [1]. This was the first time such data were available for harmonizing the table and was judged to have added significantly to the quality of the resulting publication. The Subcommittee will submit a report to *Pure and Applied Chemistry*, consisting primarily of plots (where possible) that show the variation in natural isotopic abundance, atomic weights, and standard δ-values (where possible), including data for the elements H, Li, B, C, N, O, Si, S, Cl, Fe, Se, Pd and Te. The Subcommittee was furthermore charged by the Commission to consider extending this type of survey to gaseous elements and elements involved in radioactive decay.

Recognizing the historical importance of atomic-weight values, T. B. Coplen & H. S. Peiser have prepared and will submit to *Pure and Applied Chemistry* a manuscript titled 'History of the recommended atomic-weight values from 1882 to 1997: A comparison of differences from current values to the estimated uncertainties of earlier values'. In that publication the differences between current and earlier recommended atomic atomic-weight values are compared to estimated uncertainties of the earlier values when originally determined.

On the basis of a report from the Internet working party, the Commission decided to further investigate this medium for disseminating data on atomic weights and isotopic abundances. The Commission has set up a prototype site (URL: http://www.physics.curtin.edu.au/IUPAC/index.html) which contains both general public and commission-only accessible areas. The server is located at Curtin University, Australia and is overseen by R. Loss. The site will seek to include a wide range of data types in order to evaluate its ease of use and potential impact on the scientific community.

It was noted with sadness that an esteemed former member of the Commission, Prof. H.G. Thode, had passed away. Prof. Thode served as a member of this Commission from 1963 to 1977 and was a pioneer in the measurement of sulfur isotopic abundance variations in nature. He received many awards for his work during his long and productive career among which was the Montreal Medal in chemistry.

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APPENDIX A

National metrological institutes with reference materials pertinent to atomic weights and isotopic abundances

Following the recommendations of the Commission on Atomic Weights and Isotopic Abundances of the International Union of Pure and Applied Chemistry at the 39th General Assembly in 1997 in Geneva, Switzerland, the addresses of national and international metrological institutes responsible for the production and distribution of reference materials pertinent to atomic weights and isotopic abundances are listed here.

National Institute of Standards and Technology, Standard Reference Materials Program, Room 204, Building 202, Gaithersburg, Maryland 20899-0001, USA. Tel.: +1 301 974 6776; Fax: +1 301 948 3730; E-mail: SRMINFO@nist.gov

International Atomic Energy Agency, Section of Isotope Hydrology, Wagramerstrasse 5, PO Box 100, A-1400 Vienna, Austria. Tel.: +43 1 2600 21735; Fax: +43 1 2600 7; E-mail: IAEO@iaea1.iaea.or.at

Institute for Reference Materials and Measurements, European Commission, Joint Research Centre, Retieseweg, B-2440 Geel, Belgium. Tel.: +32 14 571 617; Fax: +32 14 591 978; E-mail: imsales@irmm.jrc.be

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Errata

Commission on Atomic Weights and Isotopic Abundances (R. D. Vocke Jr). Atomic weights of the elements (Technical Report). *Pure Appl. Chem.* **71**(8), 1593–1607 (1999)

There was an error in Table 1 of the above Technical Report. The entry on Caesium should have read as follows:

Name	Atomic symbol	Atomic number	Weight
Caesium (Cesium)	Cs	55	132.90545(2)

There was also an error on the front cover of the same issue. The cover indicated that the issue contained the Plenary and Invited Lectures from the 21st IUPAC Symposium on the Chemistry of Natural Products (ISCNP-21), Beijing, China, 11–16 October 1998. In fact, these were published in the June 1999 issue. The publisher apologises for any inconvenience caused.