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**DIVISION OF INORGANIC CHEMISTRY
COMMISSION ON ATOMIC WEIGHTS**

**ATOMIC WEIGHTS
OF THE ELEMENTS
1971**

**LONDON
BUTTERWORTHS**

DIVISION OF INORGANIC CHEMISTRY

COMMISSION ON ATOMIC WEIGHTS†

ATOMIC WEIGHTS OF THE ELEMENTS

CHANGES IN ATOMIC WEIGHT VALUES

In their 1969 *Report*¹ the Commission on Atomic Weights made two important innovations: they indicated the estimated reliability of the quoted values by the mode of printing the last digit, and they added various references to seven footnotes in order further to elaborate or qualify the values given. The values then chosen have not been criticized. On the basis of work published or accepted for publication during the last two years the following changes are now recommended.

Changes in Atomic Weights

Chemical symbol	1969 atomic weight	1971 atomic weight
H	1.008 ₀	1.0079
F	18.9984	18.99840
Na	22.9898	22.98977
Al	26.9815	26.98154
P	30.9738	30.97376
K	39.10 ₂	39.09 ₈
Zn	65.3 ₇	65.38
Cs	132.9055	132.9054
Ho	164.9303	164.9304
Bi	208.9806	208.9804

Four of these ten new values have implied uncertainties one tenth of those of the 1969 values. Two of the new values have implied uncertainties one third of the 1969 values. Eight of the above changes are within the implied precision of the old values. Two are outside that range by one unit in the last decimal.

The change in the value for *hydrogen* derives from a complex problem. The most likely value relevant to a laboratory sample is 1.00797. Previously the Commission decided to round this off to 1.008₀, the final digit being subscript because the full range of normal hydrogen sources departs by more than

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0.0001 from the above value as a result of variations in isotopic abundance. In consequence of the skew distribution of abundances of deuterium in nature the value of 1.0079 encompasses all normal samples whereas the value 1.0080 does not. Added precision can therefore be incorporated by using the value 1.0079 rather than the former value of 1.008₀. Although as a rule the atomic weight values in the table should not be influenced by any variations in isotopic abundance caused by chemical processing, it is worth noting that sometimes hydrogen gas used in laboratories has been depleted of deuterium through electrolysis. The atomic weight of laboratory hydrogen is therefore at times close to 1.0079₀.

The change for *potassium* depends on a new analysis by G. Marinenko² of old chemical data by R. G. Bates and E. Wickers³ which gives additional credence to atomic weight determinations for potassium by chemical methods. The Commission therefore feels that the presently used mass spectroscopic data should not be the only basis for the published atomic weight value. Unfortunately, the two sets of chemical and mass spectroscopic data, whilst being self-consistent within each set, show unexplained discrepancies between the two sets; for this reason the Commission has decided to use a mean value rather than the mass spectroscopic value alone. This reduces the atomic weight of potassium by one part in 10⁴ to 39.09₈.

The new value for *zinc* depends on an accurate new coulometric determination by G. Marinenko and R. T. Foley⁴. Even on conservative estimates of uncertainties and unsuspected bias of the new technique an improvement in the precision of the atomic weight for zinc was possible; this is reflected in the new value of 65.38 in which the final digit is printed on line.

New nuclidic mass data assembled and assessed by A. H. Wapstra and N. B. Gove⁵ have led to improved accuracy of recommended atomic weights of some mononuclidic elements (*fluorine*, *sodium*, *aluminium* and *phosphorus*). Based on the same work, the values for *caesium* and *holmium* were adjusted by one unit in the fourth decimal figure and the value for *bismuth* by two units in the fourth decimal figure.

The Commission points out that the precision with which the atomic weights of mononuclidic elements are quoted in the tables is less than the accuracy claimed for the mass-spectrometrically determined relative atomic masses. This is partly because the precision of relative mass measurements of individual nuclides is often greater than the precision with which it has been established experimentally that minute traces of other long-lived isotopes of that element are absent in naturally occurring samples.

New data on isotopic abundances in unusual geological locations have made it desirable to add the footnote g to the elements *lithium*⁶, *magnesium*⁷, and *calcium*⁷.

Footnote b has been deleted from *neptunium*.

Information on the atomic weight of *technetium* is being withdrawn from the Table of Atomic Weights because the longer-lived isotope ⁹⁷Tc is becoming available in addition to the fission product ⁹⁹Tc. However, data for both isotopes are given in the Table of Relative Atomic Masses of Selected Isotopes.

The Commission has noted that the use of small digits to indicate an uncertainty higher than ± 1 in the last digit has led to difficulties in printing.

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For this reason the Commission now recommends that subscript digits be used for this purpose.

THE RELATIVE PRECISION OF ATOMIC WEIGHT VALUES

The relative precision with which values of the atomic weights are quoted varies widely (see *Figure 1*). In some instances, low relative precision is a necessary consequence of the known variability of isotopic abundances in normal materials (e.g. lithium, boron, etc.). However, the figure also indicates deficiencies in the data on such elements as titanium, nickel, germanium, molybdenum, palladium, tin, rhenium, and osmium.

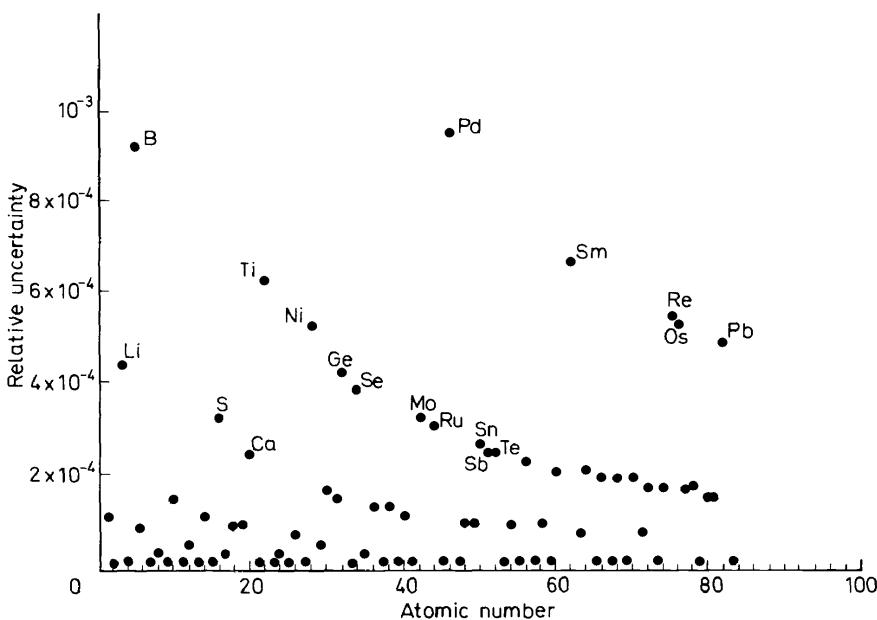


Figure 1. Relative uncertainty of the atomic weight values of the elements 1971.

In pointing to the low relative precision of data on these elements the Commission hopes to stimulate research and development work on the use of established and new techniques for redetermination of atomic weights. Calibrated isotopic abundance measurements are especially needed, and provision of standard reference materials of known isotopic abundance would also be found helpful. Renewed attempts might be made to distribute typical homogeneous materials known to be representative of the natural composition of specified elements.

SYMBOLS AND TERMINOLOGY

Simultaneously with the 1969 *Report* of the Commission on Atomic Weights¹, the Commission on Symbols, Terminology and Units of the

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TABLE OF ATOMIC WEIGHTS 1971

Scaled to the relative atomic mass, $A_{\text{r}}(^{12}\text{C}) = 12$

The values of $A_{\text{r}}(\text{E})$ given here apply to elements as they exist in materials of terrestrial origin and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ± 1 in the last digit, or ± 3 if that digit is subscript.

Alphabetical Order in English

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	—	Mercury	Hg	80	200.5 ₉
Aluminium	Al	13	26.98154 ^a	Molybdenum	Mo	42	95.9 ₄
Americium	Am	95	—	Neodymium	Nd	60	144.2 ₄
Antimony	Sb	51	121.7 ₅	Neon	Ne	10	20.17 ₉ ^c
Argon	Ar	18	39.94 ₈ ^{b, c, d, g}	Neptunium	Np	93	237.0482 ^f
Arsenic	As	33	74.9216 ^a	Nickel	Ni	28	58.7 ₁
Astatine	At	85	—	Niobium	Nb	41	92.9064 ^a
Barium	Ba	56	137.3 ₄	Nitrogen	N	7	14.0067 ^{b, c}
Berkelium	Bk	97	—	Nobelium	No	102	—
Beryllium	Be	4	9.01218 ^a	Osmium	Os	76	190.2
Bismuth	Bi	83	208.9804 ^a	Oxygen	O	8	15.999 ₄ ^{b, c, d}
Boron	B	5	10.81 _{c, d, e}	Palladium	Pd	46	106.4
Bromine	Br	35	79.904 ^e	Phosphorus	P	15	30.97376 ^a
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.0 ₉
Caesium	Cs	55	132.9054 ^a	Plutonium	Pu	94	—
Calcium	Ca	20	40.08 ^e	Polonium	Po	84	—
Californium	Cr	98	—	Potassium	K	19	39.09 ₈ ^g
Carbon	C	6	12.011 _{b, d}	Praseodymium	Pr	39	140.9077 ^a
Cerium	Ce	58	140.12	Promethium	Pm	61	—
Chlorine	Cl	17	35.453 ^c	Protactinium	Pa	91	231.0359 ^f
Chromium	Cr	24	51.996 ^e	Radium	Ra	88	226.0254 ^{f, g}
Cobalt	Co	27	58.9332 ^a	Radon	Rn	86	—
Copper	Cu	29	63.54 ₆ ^{c, d}	Rhenium	Re	75	186.2
Curium	Cm	96	—	Rhodium	Rh	45	102.9055 ^a
Dysprosium	Dy	66	162.5 ₀	Rubidium	Rb	37	85.467 ₈ ^c

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Einsteinium	Es	99	—	Ruthenium	Ru	44
Erbium	Er	68	167.2 ^c	Samarium	Sm	62
Europium	Eu	63	151.96	Scandium	Sc	21
Fermium	Fm	100	—	Selenium	Se	34
Fluorine	F	9	18.99840 ^a	Silicon	Si	14
Francium	Fr	87	—	Silver	Ag	47
Gadolinium	Gd	64	157.2 _s	Sodium	Na	11
Gallium	Ga	31	69.72	Strontium	Sr	38
Germanium	Ge	32	72.9 _s	Sulfur	S	16
Gold	Au	79	196.9665 ^a	Tantalum	Ta	73
Hafnium	Hf	72	178.4 _s	Technetium	Tc	43
Helium	He	2	4.00260 ^{b,c}	Tellurium	Te	52
Holmium	Ho	67	164.9304 ^a	Terbium	Tb	65
Hydrogen	H	1	1.0079 ^{b,d}	Thallium	Tl	81
Indium	In	49	114.82	Thorium	Th	90
Iodine	I	53	126.9045 ^a	Thulium	Tm	69
Iridium	Ir	77	192.2 _s	Tin	Tn	50
Iron	Fe	26	55.84 _s	Titanium	Ti	22
Krypton	Kr	36	83.80	Tungsten	W	74
Lanthanum	La	57	138.905 _s ^b	Uranium	U	92
Lawrencium	Lr	103	—	Vanadium	V	23
Lead	Pb	82	207.2 ^{d,s}	Wolfram	W	74
Lithium	Li	3	6.94 _s , d, e, g	Xenon	Xe	54
Lutetium	Lu	71	174.97	Ytterbium	Yb	70
Magnesium	Mg	12	24.305 ^{c,s}	Yttrium	Y	39
Manganese	Mn	25	54.9380 ^a	Zinc	Zn	30
Mendeleyium	Md	101	—	Zirconium	Zr	40

^a Element with only one stable nuclide.

^b Element with one predominant isotope (about 99 to 100 per cent abundance); errors in abundance determinations have a correspondingly small effect on the confidence in the value of $A_i(E)$.

^c Element for which the value of $A_i(E)$ derives its reliability from calibrated measurements i.e. from comparisons with synthetic mixtures of known isotopic composition.

^d Element for which known variations in isotopic abundance in terrestrial material prevent a more precise atomic weight being given; $A_i(E)$ values should be applicable to any 'normal' material.

^e Element for which values of A_i may be found in commercially available products that differ from the tabulated value of $A_i(E)$ because of inadvertent or undisclosed changes of isotopic composition.

^f Element for which the value of A_i is that of the most commonly available long-lived nuclides.

^g Element for which geological specimens are known in which the element has an anomalous isotopic composition.

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TABLE OF ATOMIC WEIGHTS 1971

Scaled to the relative atomic mass, $A_r(^{12}\text{C}) = 12$

The values of $A_r(E)$ given here apply to elements as they exist in materials of terrestrial origin and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ± 1 in the last digit, or ± 3 if that digit is subscript.

Order of Atomic Number

Atomic number	Name	Symbol	Atomic weight	Atomic number	Name	Symbol	Atomic weight
1 Hydrogen	H		1.0079 ^{b,d}	53 Iodine	I		126.9045 ^a
2 Helium	He		4.00260 ^{b,c}	54 Xenon	Xe		131.30
3 Lithium	Li		6.94 ₁ ^{c,d,e,g}	55 Caesium	Cs		132.954 ^a
4 Beryllium	Be		9.01218 ^a	56 Barium	Ba		137.3 ₄
5 Boron	B		10.81 ^{c,d,e}	57 Lanthanum	La		138.905 ₅
6 Carbon	C		12.011 ^{b,d}	58 Cerium	Ce		140.12
7 Nitrogen	N		14.0067 ^{b,c}	59 Praseodymium	Pr		140.9077 ^a
8 Oxygen	O		15.999 ₄ ^{b,c,d}	60 Neodymium	Nd		144.2 ₄
9 Fluorine	F		18.99840 ^a	61 Promethium	Pm		—
10 Neon	Ne		20.17 ₉ ^e	62 Samarium	Sm		150.4
11 Sodium	Na		22.98977 ^a	63 Europium	Eu		151.96
12 Magnesium	Mg		24.305 ^{c,g}	64 Gadolinium	Gd		157.2 ₅
13 Aluminium	Al		26.98154 ^a	65 Terbium	Tb		158.954 ^a
14 Silicon	Si		28.08 ₆ ^d	66 Dysprosium	Dy		162.5 ₀
15 Phosphorus	P		30.97376 ^a	67 Holmium	Ho		164.9304 ^a
16 Sulfur	S		32.06 ^d	68 Erbium	Er		167.2 ₆
17 Chlorine	Cl		35.453 ^c	69 Thulium	Tm		168.9342 ^a
18 Argon	Ar		39.94 ₈ ^{b,c,d,g}	70 Ytterbium	Yb		173.0 ₄
19 Potassium	K		39.09 ₈	71 Lutetium	Lu		174.97
20 Calcium	Ca		40.08 ₈	72 Hafnium	Hf		178.4 ₉
21 Scandium	Sc		44.9559 ^a	73 Tantalum	Ta		180.947 ₉
22 Titanium	Ti		47.9	74 Wolfram (Tungsten)	W		183.8 ₅

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23	Vanadium	50.941 ^{b,c}	Re	Rhenium
24	Chromium	51.996 ^c	Os	Osmium
25	Manganese	54.9380 ^a	Ir	Iridium
26	Iron	55.84 ₇	Pt	Platinum
27	Cobalt	58.9332 ^a	Au	Gold
28	Nickel	58.7 ₁	Hg	Mercury
29	Copper	63.54 ₆	Tl	Thallium
30	Zinc	65.38	Pb	Lead
31	Gallium	69.72	Bi	Bismuth
32	Germanium	72.5 ₉	Po	Polonium
33	Arsenic	74.9216 ^a	At	Astatine
34	Selenium	78.9 ₆	Rn	Radon
35	Bromine	79.904 ^c	Fr	Francium
36	Krypton	83.80	Ra	Radium
37	Rubidium	85.467 ^c	Ac	Actinium
38	Strontium	87.62 ^f	Th	Thorium
39	Yttrium	88.9059 ^a	Pa	Protactinium
40	Zirconium	91.22	U	Uranium
41	Niobium	92.9064 ^a	Np	Neptunium
42	Molybdenum	95.9 ₄	Pu	Plutonium
43	Technetium	—	Am	Americium
44	Ruthenium	101.0 ₇	Cm	Curium
45	Rhodium	102.9055 ^a	Bk	Berkelium
46	Palladium	106.4	Cf	Californium
47	Silver	107.868 ^c	Es	Einsteinium
48	Cadmium	112.40	Fm	Fermium
49	Indium	114.82	Md	Mendelevium
50	Tin	118.6 ₉	No	Nobelium
51	Antimony	121.7 ₅	Lr	Lawrencium
52	Tellurium	127.6 ₀	Te	

^a Element with only one stable nuclide.
^b Element with one predominant isotope (about 99 to 100 per cent abundance); errors in abundance determinations have a correspondingly small effect on the confidence in the value of $A_t(E)$.

^c Element for which the value of $A_t(E)$ derives its reliability from calibrated measurements (i.e. from comparisons with synthetic mixtures of known isotopic composition).

^d Element for which known variations in isotopic abundance in terrestrial material prevent a more precise atomic weight being given. $A_t(E)$ values should be applicable to any 'normal' material.

^e Element for which values of A_t may be found in commercially available products that differ from the tabulated value of $A_t(E)$ because of inadvertent or undisclosed changes of isotopic composition.

^f Element for which geological specimens are known in which the element has an anomalous isotopic composition.

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TABLE OF RELATIVE ATOMIC MASSES OF SELECTED NUCLIDES

Name	Symbol	Atomic number	Mass number	Relative atomic mass	Half-life*	
Hydrogen	H	1	1	1.007825		
(Deuterium)	(D)	1	2	2.014102		
(Tritium)	(T)	1	3	3.016050	12.33	a
Helium	He	2	3	3.016030		
			4	4.00260		
Lithium	Li	3	6	6.01512		
			7	7.01600		
Boron	B	5	10	10.01294		
			11	11.00931		
Carbon	C	6	12	12 Exactly		
			13	13.003355		
			14	14.00324	5730	a
Nitrogen	N	7	14	14.003074		
			15	15.00011		
Oxygen	O	8	16	15.994915		
			17	16.999133		
			18	17.99916		
Magnesium	Mg	12	24	23.98504		
			25	24.98584		
			26	25.98259		
Silicon	Si	14	28	27.97693		
			29	28.97650		
			30	29.97377		
Sulfur	S	16	32	31.97207		
			33	32.97146		
			34	33.96787		
			36	35.96708		
Argon	Ar	18	36	35.96755		
			38	37.96273		
			40	39.96238		
Calcium	Ca	20	40	39.96259		
			42	41.9586		
			43	42.9588		
			44	43.9555		
			46	45.9537		
			48	47.9525		
Copper	Cu	29	63	62.9296		
			65	64.9278		
Strontium	Sr	38	84	83.9134		
			86	85.9093		
			87	86.9089		
			88	87.9056		
Technetium	Tc	43	97	96.9064	2.6 × 10 ⁶	a
			99	98.9062	2.13 × 10 ⁵	a
Promethium	Pm	61	145	144.9128	18	a
			147	146.9152	2.6234	a

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Name	Symbol	Atomic number	Mass number	Relative atomic mass	Half-life*
Lead	Pb	82	204	203.9730	
			206	205.9745	
			207	206.9759	
			208	207.9767	
Polonium	Po	84	209	208.9824	102
			210	209.9829	138.38
Astatine	At	85	210	209.987	8.1
Radon	Rn	86	222	222.0176	3.824
Francium	Fr	87	223	223.0198	22
Radium	Ra	88	226	226.0254	1.60×10^3
Actinium	Ac	89	227	227.0278	21.77
Thorium	Th	90	232	232.0381	1.40×10^{10}
Protactinium	Pa	91	231	231.0359	3.25×10^4
Uranium	U	92	233	233.0397	1.59×10^5
			234	234.0410	2.44×10^5
			235	235.0439	7.10×10^8
			236	236.0456	2.42×10^7
			238	238.0508	4.49×10^9
Neptunium	Np	93	237	237.0482	2.14×10^6
Plutonium	Pu	94	238	238.0496	87.8
			239	239.0522	2.439×10^4
			240	240.0538	6.54×10^3
			241	241.0569	15
			242	242.0588	3.87×10^5
			244	244.0642	8.3×10^7
Americium	Am	95	241	241.0568	433
Curium	Cm	96	243	243.0614	7.37×10^3
			242	242.0589	163
			243	243.0614	28
			244	244.0628	17.9
			245	245.0655	8.7×10^3
			246	246.0672	4.65×10^3
			247	247.0704	1.54×10^7
			248	248.0724	3.4×10^5
			250	250.0784	1.1×10^4
			247	247.0703	1.4×10^3
Berkelium	Bk	97	249	249.0750	311
Californium	Cf	98	251	251.0796	900
			252	252.0817	2.64
Einsteinium	Es	99	254	254.0874	60
			253	253.0848	20.47
Fermium	Fm	100	254	254.0881	276
Mendelevium	Md	101	257	257.0951	82
			257	257.0956	5
Nobelium	No	102	258	not given	55
Lawrencium	Lr	103	255	255.0933	3.2
			256	256.0986	35

* a = year; d = day; hr = hour; min = minute; s = second

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Division of Physical Chemistry of IUPAC published its *Manual of Symbols and Terminology for Physicochemical Quantities and Units*⁸. Section III on the Explanation of Terms published with the former Report¹ should be considered superseded by the recommendations of the latter⁸. In particular the term 'atomic weight of an element' is an alternative for the term 'relative atomic mass of an element' which is 'the ratio of the average mass per atom of a natural nuclidian composition of an element to $\frac{1}{12}$ of the mass of an atom of nuclide ^{12}C '. Example: $A_r(\text{Cl}) = 34.453$. The concept of relative atomic mass may be extended to other specified nuclidian compositions, but the natural nuclidian composition is assumed unless some other composition is specified.' Readers should note especially that atomic weights are thus dimensionless numbers.

The values of $A_r(E)$ given in the Table of Atomic Weights apply to elements as they exist in 'normal materials'. A 'normal material' is one that contains as a major constituent a specified element with an atomic weight value that does not display a significant difference from the accepted value of that atomic weight because of:

- (i) its radiogenic source;
- (ii) its extraterrestrial origin;
- (iii) artificial isotopic fractionation;
- (iv) artificial nuclear reaction;
- (v) a rare geological occurrence in small quantity.

RELATIVE ATOMIC MASSES OF SELECTED NUCLIDES

In this 1971 Report the Commission has expanded the Table of Relative Atomic Masses of Selected Nuclides (formerly called Table of Atomic Masses of Selected Isotopes) to include the following: (i) all stable isotopes of elements whose isotopic composition is known to vary in nature or to have been varied extensively as a result of artificial processes, that is all those elements that are given the footnotes d, e or g in the Table of Atomic Weights; and (ii) all those radioactive nuclides previously included in the 1969 Tables of Selected Radioactive Isotopes and of Atomic Masses of Selected Isotopes (with the exception of ^{143}Pm). In this way users can calculate the atomic weight characteristic of specific samples of known isotopic contents. The publication of the Table of Selected Radioactive Isotopes is discontinued but the half-life values of the radioisotopes are included in the Table of Relative Atomic Masses of Selected Nuclides. These half-lives are taken from a recently assembled and critically evaluated compilation by N. E. Holden and F. W. Walker⁹.

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